SECOND YEAR COURSES CATALOG



Academic year 2023-2024

September 20, 2023 issue

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CORE CURRICULUM COURSES

2CC1000 – Control theory

Instructors : **Pedro Rodriguez-Ayerbe, Maria Makarova**
Department : **DÉPARTEMENT AUTOMATIQUE**
Language of instruction : **ENGLISH, FRENCH**
Type of course : **Common course**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES, CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **31,50**

Description

The physical systems generally rely on the fundamental concept of a feedback loop, allowing them to be controlled and giving them a behavior that is as insensitive as possible to environmental disturbances. The general objective of this course is to provide students with the concepts and skills enabling them to understand the structure and interactions within existing dynamic systems or along with their design. They will also be able to process information, design a control law to meet specifications, and analyze its performance and robustness. To achieve this, the students must first be able to define a model (or a set of models), highlighting the variables influencing the state of this system (inputs), the measures allowing access to this state, and variables to which the specifications relate (outputs), as well as the relationships between these variables. Then, in a second step, and from the analysis of the inputs that can be controlled (commands) or those that are undergone (disturbances), students will have to design a control law in order to ensure the expected performances. The last step in this course will concern the analysis of the robustness of the determined control law.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Core curriculum “Modelling” (ST2), semester-long course “Convergence, integration, probability" and "partial differential equations”, core curriculum “Signal processing” (ST4)

Syllabus

Course overview:
1. Introduction

a. Interest of the closed loop, key notions of control, disturbance rejection
b. Classical frequency approach vs more current and generic temporal approach
c.Application examples
d. General theorems: intrinsic limitations of the ideal loop (needs to formalize, trade-off to be made)

2. State-space representation
a. Reminders
b. Properties (controllability, observability)
c. Linearized / nonlinear links - implementation of the control law on the nonlinear model

3. State feedback control law design
a. Control by pole placement in the monovariable case, reference tracking and accuracy
b. Linear Quadratic controller (LQ control)

c. Case of measurable disturbances (disturbance rejection)
d. LQ control with integral action

4. Estimated state feedback control
a. Observer by pole placement
b. Kalman filter (LQ control duality)
c. Linear Quadratic Gaussian controller (LQG) – Separation theorem

5. Performance and robustness analysis of a control law
a. Reminders: links with the transfer function
b. Equivalent controller for the LQ and LQG controllers.
c. Small gain theorem
d. Definition of multivariable stability margins.
e. Special case of monovariable stability margins
f. Special case of the LQ and LQG controllers. Loop Transfert Recovery (LTR)
g. Special case of margins for classical frequential controllers (e.g. phase-lead, PI and PID)

6. Industrial conference: open and current issues and problems of control in industry

Class components (lecture, labs, etc.)

12h lectures, 9h workclasses, 6h lab works, 1.5h industrial lectures

- Saclay campus: lectures are structured based on 8 tracks with about 100 students per track, 7 tracks in French, 1 track in English.
- Rennes Campus: lectures are given in French with specific features to allow students with weak French level to follow them. Support sessions in English are also scheduled
- Metz campus: lectures are given in French.

Grading

Knowledge assessment:

- Lab works are mandatory activities
- Report of lab work & final written exam (3h) with calculator, handouts and personal notes authorized.
- Notation: lab work: 25%, final exam: 75%, attendance checked during workclasses and lab work, possible penalty.

Skills assessment:

- The C1 and C2 skills will be evaluated by means of the lab work and final exam. The text of these activities will clearly highlight the sections and questions related to each of these competencies.
- The C2.4 skill will be more specifically evaluated during the lab work activities.
- All the tasks for validating these two competencies will be explained by the teaching staff at the beginning of the first lecture.

Course support, bibliography

Handouts:

- Handout “Control theory” in French
- Control theory glossary French-English and English-French
- Slides shown during the lectures

Bibliography:

1. J.J. D’Azzo & C.H. Houpis - "Linear Control System. Analysis and Design" - 3e ed., Mc Graw-Hill, 1988.
2. P. Borne, G. Dauphin-Tanguy, J.-P. Richard, F. Rotella et I. Zambettakis - "Analyse et régulation des processus industriels. Tome 1. Régulation continue, Tome 2. Régulation numérique" - Éditions Technip, 1993.
3. J.B. Deluche - "Automatique. De la théorie aux applications industrielles. Tome 2 : Systèmes continus" - Edipol, 2000.
4. J.M. Flaus - "La régulation industrielle" - Hermès, 1994.
5. G.F. Franklin, J.D. Powell, A. Emami-Naeini - "Feedback Control of Dynamic Systems" - 7° ed., Ed. Pearson Publishing Company, 2014.

6. B. Friedland - "Control system design" – Mc Graw-Hill, 1986.
7. Ph. de Larminat - "Automatique. Commande des systèmes linéaires" - Hermès, 1996.
8. L. Maret - " Régulation automatique" - Presses Polytechniques Romandes, 1987.
9. K. Ogata - "Modern Control Engineering" - 5e éd., Ed. Pearson Education International, 2009.
10. A. Rachid - "Systèmes de régulation" - Masson 1996.
11. M. Zelazny, F. Giri et T. Bennani - "Systèmes asservis : commande et régulation" - Eyrolles, 1993.

Resources

- Teaching staff:

• Lectures Saclay campus: Antoine Chaillet, Didier Dumur, Hugo Lhachemi, Maria Makarova, Cristina Maniu, Pedro Rodriguez-Ayerbe, Sihem Tebbani, Cristina Vlad

• Workclasses Saclay campus: Antoine Chaillet, Didier Dumur, Maria Makarova, Cristina Maniu, Cristina Vlad, Sorin Olaru, Pedro Rodriguez-Ayerbe, Guillaume Sandou, Hugo Lhachemi, Stéphane Font, Jacques Antoine, Jing Dai, Maxime Pouilly-Cathelain, Adnane Saoud

• Lectures Rennes campus: Romain Bourdais

• Workclasses Rennes campus: Stanislav Aranovskiy, Hervé Guéguen, Marie-Anne Lefebvre, Nabil Sadou, Romain Boudais

• Lectures Metz campus: Jean-Luc Colette

- Maximum enrollment Workclasses Saclay campus: 35 students

- Equipment-specific classrooms (Saclay campus): capacity of 100 students per half day on experimental platforms

- Software: Matlab (during Lab work)

Learning outcomes covered on the course

After completion of this course, students will be able to:

1. Understand and analyze the interest of a closed-loop control structure

2. Model the behavior of a dynamic system by a time representation (state-state representation) or possibly a frequential one:

• choose a model (or a set of models) suitable to the control and/or analysis objective (linearization, model reduction, etc.)
• validate the relevance of the model (or of the set of proposed models)

3. Design control laws based on the state-space representation of the system, if necessary, by the synthesis of an observer.

• analyze the characteristics of the initial system and compare them to the specifications
• choose and design the appropriate control law
• determine an observer allowing to estimate the unmeasured state variables
• validate in simulation and experimentally the control law and criticize the obtained results
• analyze the performance and robustness of control law

4. Use simulation software to implement theoretical developments and validate control laws (particularly through experimental work)

5. Master scientific and technical communication (through the report of lab work)

Description of the skills acquired at the end of the course

Validated skills:
- Concerning the skill C1 "Analyze, design and build complex systems with scientific, technological, human and economic components", evaluated in this module:

* "Model the behaviour of a dynamic system by means of a time domain or frequency domain representation" is included in the skill C1.2 "Use and develop appropriate models, choose the right modelling scale and the relevant simplifying hypotheses to deal with a problem"

* "Analyse the time and/or frequency domain behaviour of a system and the effects of feedback" is included in the skill C1.1 "Study a problem as a whole and an overall situation. Identify, formulate and analyse a problem in its scientific, economic and human dimensions"

* "Determine a control law by state feedback (completed if necessary by the synthesis of an observer), in order to satisfy a temporal and/or frequential specification" is included in the skill C1.4 "Specify, design, implement and validate all or part of a complex system"

* "Validate a control law by means of simulation or experiments and critisize the obtain results" is included in the skills C1.3 "Solve a problem by means of approximation, simulation and experiments"

- Concerning the skill C2 "Develop in-depth skills in an engineering field and in a family of professions", evaluated in this module:

* "Model the behaviour of a dynamic system" and Analyzing the characteristics of the initial system and comparing them to the specifications" requires an appropriation of the field of application considered together with its constraints, and is therefore part of C2.2 "Importing knowledge from other fields or disciplines" and C2.3 “Identify and independently acquire the required new knowledge and skills”

* "Analyze the performance and robustness of control laws" is part of C2.4 "Produce data and develop knowledge according to a scientific approach"

* "Use simulation software to implement theoretical developments and validate control laws (in particular through experimental work)" is part of C2.4 "Producing data and developing knowledge according to a scientific approach”

- "Master scientific and technical communication (through reports during lab works)" is included in the skill C7.1 "Render complex content intelligible. Structure one’s ideas and arguments. Synthesize and see the bigger picture". This skill is not evaluated in this module.

Evaluation of the learning outcomes
Skills C1 and C2 will be evaluated in two different situations:

- Two lab work sessions will enable evaluating all these three learning outcomes, students having a real process to model, analyse and control. In particular, this pedagogical method allows students to experience experimental training and validation of the modelling and design approach

- A final exam will also confront students with a real problem of a process that should be modelled, analysed and controlled. The emphasis will be less on experimental aspects than on the ability to satisfy an industrial problem through its specifications.

The skill C2.4 will be more specifically assessed during the lab work sessions, as well as during personal work (requiring the implementation of the process via a simulation software) between the two lab work sessions.

The skill C7 will not be evaluated, but it will be more specifically handled through the report following the lab work sessions

2CC1005 – Control theory - DUAL

Instructors : **Pedro Rodriguez-Ayerbe, Maria Makarova**
Department : **DÉPARTEMENT AUTOMATIQUE**
Language of instruction : **FRENCH**
Type of course : **Common course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **31,50**

Description

The physical systems generally rely on the fundamental concept of a feedback loop, allowing them to be controlled and giving them a behavior that is as insensitive as possible to environmental disturbances. The general objective of this course is to provide students with the concepts and skills enabling them to understand the structure and interactions within existing dynamic systems or along with their design. They will also be able to process information, design a control law to meet specifications, and analyze its performance and robustness. To achieve this, the students must first be able to define a model (or a set of models), highlighting the variables influencing the state of this system (inputs), the measures allowing access to this state, and variables to which the specifications relate (outputs), as well as the relationships between these variables. Then, in a second step, and from the analysis of the inputs that can be controlled (commands) or those that are undergone (disturbances), students will have to design a control law in order to ensure the expected performances. The last step in this course will concern the analysis of the robustness of the determined control law.

Prerequisites (in terms of CS courses)

Core curriculum “Modelling” (ST2), semester-long course “Convergence, integration, probability" and "partial differential equations”

Syllabus

Course overview:

1. Introduction

   a. Interest of the closed loop, key notions of control, disturbance rejection
   b. Classical frequency approach vs more current and generic temporal approach
   c. Application examples
   d. General theorems: intrinsic limitations of the ideal loop (needs to formalize, trade-off to be made)

2. State-space representation

   a. Reminders
   b. Properties (controllability, observability)
   c. Linearized / nonlinear links - implementation of the control law on the nonlinear model

3. State feedback control law design

   a. Control by pole placement in the monovariable case, reference tracking and accuracy
   b. Linear Quadratic controller (LQ control)
   c. Case of measurable disturbances (disturbance rejection)
   d. LQ control with integral action

4. Estimated state feedback control

   a. Observer by pole placement
   b. Kalman filter (LQ control duality)
   c. Linear Quadratic Gaussian controller (LQG) – Separation theorem

5. Performance and robustness analysis of a control law

    a. Reminders: links with the transfer function
    b. Equivalent controller for the LQ and LQG controllers.
    c. Small gain theorem
    d. Definition of multivariable stability margins.
    e. Special case of monovariable stability margins
    f. Special case of the LQ and LQG controllers. Loop Transfert Recovery (LTR)
    g. Special case of margins for classical frequential controllers (e.g. phase-lead, PI and PID)

6. Industrial conference: open and current issues and problems of control in industry

Class components (lecture, labs, etc.)

12h lectures, 9h workclasses, 6h lab works, 1.5h industrial lectures.

All courses are given in French.

Grading

Knowledge assessment:

- Lab works are mandatory activities
- Report of lab work & final written exam (3h) with calculator, handouts and personal notes authorized.
- Notation: lab work: 25%, final exam: 75%, attendance checked during workclasses and lab work, possible penalty.

Skills assessment:

- The C1 and C2 skills will be evaluated by means of the lab work and final exam. The text of these activities will clearly highlight the sections and questions related to each of these competencies.
- The C2.4 skill will be more specifically evaluated during the lab work activities.
- All the tasks for validating these two competencies will be explained by the teaching staff at the beginning of the first lecture.

Course support, bibliography

Handouts:

- Handout “Control theory” in French
- Control theory glossary French-English and English-French
- Slides shown during the lectures

Bibliography:

1. J.J. D’Azzo & C.H. Houpis - "Linear Control System. Analysis and Design" - 3e éd., Mc Graw-Hill, 1988.
2. P. Borne, G. Dauphin-Tanguy, J.-P. Richard, F. Rotella et I. Zambettakis - "Analyse et régulation des processus industriels. Tome 1. Régulation continue, Tome 2. Régulation numérique" - Éditions Technip, 1993.
3. J.B. Deluche - "Automatique. De la théorie aux applications industrielles. Tome 2 : Systèmes continus" - Edipol, 2000.
4. J.M. Flaus - "La régulation industrielle" - Hermès, 1994.
5. G.F. Franklin, J.D. Powell, A. Emami-Naeini - "Feedback Control of Dynamic Systems" - 7° ed., Ed. Pearson Publishing Company, 2014.
6. B. Friedland - "Control system design" – Mc Graw-Hill, 1986.
7. Ph. de Larminat - "Automatique. Commande des systèmes linéaires" - Hermès, 1996.
8. L. Maret - " Régulation automatique" - Presses Polytechniques Romandes, 1987.
9. K. Ogata - "Modern Control Engineering" - 5e éd., Ed. Pearson Education International, 2009.
10. A. Rachid - "Systèmes de régulation" - Masson 1996.
11. M. Zelazny, F. Giri et T. Bennani - "Systèmes asservis : commande et régulation" - Eyrolles, 1993.

Resources

- Teaching staff: Cristina Vlad
- Lab work realized on experimental platforms
- Software: Matlab (during Lab work)

Learning outcomes covered on the course

After completion of this course, students will be able to:

1. Understand and analyze the interest of a closed-loop control structure

2. Model the behavior of a dynamic system by a time representation (state-state representation) or possibly a frequential one:

• choose a model (or a set of models) suitable to the control and/or analysis objective (linearization, model reduction, etc.)
• validate the relevance of the model (or of the set of proposed models)

3. Design control laws based on the state-space representation of the system, if necessary, by the synthesis of an observer.

• analyze the characteristics of the initial system and compare them to the specifications
• choose and design the appropriate control law
• determine an observer allowing to estimate the unmeasured state variables
• validate in simulation and experimentally the control law and criticize the obtained results
• analyze the performance and robustness of control law

4. Use simulation software to implement theoretical developments and validate control laws (particularly through experimental work)

5. Master scientific and technical communication (through the report of lab work)

Description of the skills acquired at the end of the course

Validated skills:
- Concerning the skill C1 "Analyze, design and build complex systems with scientific, technological, human and economic components", evaluated in this module:

> * "Model the behaviour of a dynamic system by means of a time domain or frequency domain representation" is included in the skill C1.2 "Use and develop appropriate models, choose the right modelling scale and the relevant simplifying hypotheses to deal with a problem"
>
> * "Analyse the time and/or frequency domain behaviour of a system and the effects of feedback" is included in the skill C1.1 "Study a problem as a whole and an overall situation. Identify, formulate and analyse a problem in its scientific, economic and human dimensions"
>
> * "Determine a control law by state feedback (completed if necessary by the synthesis of an observer), in order to satisfy a temporal and/or frequential specification" is included in the skill C1.4 "Specify, design, implement and validate all or part of a complex system"
>
> * "Validate a control law by means of simulation or experiments and critisize the obtain results" is included in the skills C1.3 "Solve a problem by means of approximation, simulation and experiments"

- Concerning the skill C2 "Develop in-depth skills in an engineering field and in a family of professions", evaluated in this module:

> * "Model the behaviour of a dynamic system" and Analyzing the characteristics of the initial system and comparing them to the specifications" requires an appropriation of the field of application considered together with its constraints, and is therefore part of C2.2 "Importing knowledge from other fields or disciplines" and C2.3 “Identify and independently acquire the required new knowledge and skills”

* "Analyze the performance and robustness of control laws" is part of C2.4 "Produce data and develop knowledge according to a scientific approach"

* "Use simulation software to implement theoretical developments and validate control laws (in particular through experimental work)" is part of C2.4 "Producing data and developing knowledge according to a scientific approach”

- "Master scientific and technical communication (through reports during lab works)" is included in the skill C7.1 "Render complex content intelligible. Structure one’s ideas and arguments. Synthesize and see the bigger picture". This skill is not evaluated in this module.

Evaluation of the learning outcomes
Skills C1 and C2 will be evaluated in two different situations:

- Two lab work sessions will enable evaluating all these three learning outcomes, students having a real process to model, analyse and control. In particular, this pedagogical method allows students to experience experimental training and validation of the modelling and design approach

- A final exam will also confront students with a real problem of a process that should be modelled, analysed and controlled. The emphasis will be less on experimental aspects than on the ability to satisfy an industrial problem through its specifications.

The skill C2.4 will be more specifically assessed during the lab work sessions, as well as during personal work (requiring the implementation of the process via a simulation software) between the two lab work sessions.

The skill C7 will not be evaluated, but it will be more specifically handled through the report following the lab work sessions

2CC3000 – Optimization

Instructors : **Jean-Christophe Pesquet**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **Common course**
Campus : **CAMPUS DE METZ, CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **31,50**

Description

This course will explore various fundamental notions of both continuous and discrete optimization.

The following topics will be addressed and implemented: formulation of optimization problems, existence conditions for global and local minimizers, convexity, duality, Lagrange multipliers, first-order methods, linear programming, integer linear programming, branch and bound approaches, preliminary stochastic optimization concepts.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Basics in functional analysis, differential calculus, and probability (convergence, integration and probability course), knowledge of a programming environments

Syllabus

1. Optimization basics
1.1 Introductory notions
    1.2 Existence of minimizers
    1.3 Convexity
    1.4 Some iterative algorithms
    1.5 Duality

2. Linear programming
3. Integer linear programming
4. Lagrange multipliers method
5. Stochastic Optimization

Class components (lecture, labs, etc.)

This course combines lectures and exercise/practical classes.
This represents 21 hours of lectures, 7.5 of exercise classes, and 3 hours of final exam.
Parts 3 and 5 of the course will be self-studied with an appropriate assessment process.

Grading

The grading will be based on a continuous evaluation process (40%) and the final written exam (60%). In case of a justified absence to intermediary examinations, the grades of the latters are replaced by the grade of the final examination.

Course support, bibliography

D. P. Bertsekas, Nonlinear Programming, 3rd Edition. Athena Scientific, 2016. ISBN:978-1-886529-05-2
H.H. Bauschke and P. L. Combettes, Convex Analysis and Monotone Operator Theory in Hilbert Spaces, 2nd Edition. Springer, 2017. ISBN: 978-3-319-48311-5

Resources

Software equired: MATLAB, Python,...

Learning outcomes covered on the course

Upon completion of this course, the students will be able to :

address a wide range of concrete optimization problems arising either in a scientific or industrial context.
Formulate the problem in a suitable manner, to handle it numerically by using existing methods,
validate and interpret the solution with regards to the initial problem.

Description of the skills acquired at the end of the course

Intermediary level skills in optimization both at the mathematical level (C1) and the algorithmic level (C6)

2CC3005 – Optimisation - DUAL

Instructors : **Charles Soussen**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **Common course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **31,50**

Description

Optimization arises in many domains including science, mathematics, engineering, economy and finance. For instance, the problems of stock management, resource allocation, control of mechanical structures, and data analysis may all be addressed as optimization problems. Although these problems are of various nature, they can all be formulated as the minimization of a cost function over a given domain and under a set of constraints. Nevertheless, there are many existing optimization methods depending on the structure of the problem at hand.

This course aims at teaching a comprehensive overview of the classical optimization approaches and algorithms. The objective is to provide the background that will allow the participants to practically address the various optimization problems they might encounter, and help them choosing the adequate algorithm. The lecture will cover local and simple global optimization methods. The topics will include gradient-based algorithms, constrained optimization, least-squares methods, and discrete optimization.

Prerequisites (in terms of CS courses)

There are no official prerequisites for this course. However, the students are expected to have basic knowledge of linear algebra and matrix computation.

Syllabus

1. Unconstrained optimization : gradient-based algorithms, Newton and quasi-Newton algorithms.
2. Least squares problems.
3. Constrained optimization.
4. Global and discrete optimization.

Class components (lecture, labs, etc.)

Teaching is composed of courses and labs (TD). The labs cover computional aspects (solve KKT systems, in particular) and the practical use of the Matlab optimization solvers.

Grading

Written final exam (2 hours, 100 %)

The evaluation of the course will be based on a written exam (2 hours). The exam may cover all topics seen during the lectures and practical sessions, with a focus on local optimization algorithms: knowledge of algorithms,

simple calculations, practical knowledge of how to call optimization solvers (in this case, the help of the matlab solver will be given) using matlab pseudo-code, interpretation of the results of numerical simulations. Only basic knowledge is requested regarding global and discrete optimization. The evaluation will be possibly related to the content of the lab sessions.

No documents allowed. Computers and calculators will be forbidden. Mobile phones must be switched off.

Course support, bibliography

1. J. Nocedal and J. S. Wright, Numerical optimization, 2nd edition, Springer Verlag, New York, Jul. 2006.
2. R. Fletcher, Practical Methods of Optimization, 2nd edition, Wiley, 2000
3. A. Björck, Numerical Methods for Least Squares Problems, Society for Industrial and Applied Mathematics, Philadephia, Apr. 1996.
4. R. Horst, P. M. Pardalos, and V. T. Nguyen, Introduction to Global Optimization, 2nd edition, Springer, Dec. 2000.

Resources

- Complete slides
- Software tools: see matlab documentation (optimtool)
- Related Courses: see the books in bibliography

Learning outcomes covered on the course

The course aims to introduce students to the main concepts and numerical methods of numerical optimization. The course is mainly focused on local optimization, although some general principles of global optimization algorithms are sketched as well.

Description of the skills acquired at the end of the course

The exam contributes to validate skills C1 and C6.

It is expected that by the end of the course, the students will have a good knowledge of the main algorithms and will be able to carry out simple calculations : calculation of gradients, Hessians, resolution of simple optimization problems, e.g. by expressing the KKT conditions and solving the related system. Additionally, the students should have a practical knowledge of how to call Matlab optimization solvers and should be able to give an interpretation of the numerical results.

SEMESTER LONG COURSES

2SL1000 – Economics

Instructors : **Pascal DA COSTA**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **ENGLISH, FRENCH**
Type of course : **long semester course**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES, CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **21,00**

Description

You have probably already read the economic press and heard about economic variables and concepts (drivers of growth, inflation-unemployment relationship, types of competition, European Central Bank and other economic institutions): it is now time to clearly define all this and finally grasp the complexity of economic debates. In doing so, you will all meet, at least once in your schooling, the opinion of economists on the major problems and debates that affect our society.
The main goal of the class of economics is to provide the basic concepts required to understand and analyze the economic environment. Each topic will be covered with real facts and real, historical and recent statistics, and then explained with the theories of economics (you will see that the theoretical controversies are quite common in economics).
This course also aims to train you in the challenges of the ecological transition, through its economic aspects and the concepts of this field (externalities, cost of inaction, incentive policies, growth and development, etc.): The UN Sustainable Development Goals addressed in this course are thus #7 Energy, #8 Growth, #9 Industry and Innovation, #10 Inequality, #12 Sustainable Consumption and Production, #13 Climate.

Quarter number

ST5

Prerequisites (in terms of CS courses)

None

Syllabus

1- History of economic thought: Mathematical modeling of economic facts. Validation by econometrics.
2- Microeconomics: Markets structures and regulations. Market failures. Positive and negative externalities: innovation and pollution. Natural monopoly. Price discrimination. Asymmetric information. Games theory.
3- Monetary economics: From the economy of debt to the economy of financial markets. The role of money. The role of the Central Bank and commercial banks in the financing of the economy.
4- Fluctuations and economic policies: Monetary policy, Fiscal policy. Unemployment.
5- International economics and globalization: International trade: regulation of world trade, theories of international trade. International finance: exchange rate, balance of payments, international monetary and financial systems (the model IS-without LM in open economy).
6- Economics of growth, innovations, inequality. Economics of the sustainable development.

Class components (lecture, labs, etc.)

10.5 hours of Lecture
9 hours of Tutorials
2 hours of Exams / Test

or Integrated classes (in French only) (lectures + tutorials) (limited places)

Courses in French or English (to be chosen by the student).

Grading

• Intermediate Exam (IE): 20% of the final grade
• 1 Final Exam (FE): without document, 2 hours duration: 80% of the final grade (1 or 2 exercises + 1 question of reflection)
• Grade = Max (0,2.IE + 0,8.FE , FE)

Course support, bibliography

Teaching Material and Textbooks:
- Course reader
- Begg, Fischer, Dornbusch (2002) Macroéconomie, Dunod.
- Begg, Fischer, Dornbusch (2002) Microéconomie, Dunod.
- Blanchard, Cohen (2002) Macroéconomie, Pearson Education.
- Burda, Wyplosz (1998) Macroéconomie : une perspective européenne, Boeck Université.
- da Costa (2013) Etats-Unis, Europe, Chine : des Etats au coeur des crises économiques et financières mondiales, l'Harmattan.
- Mucchielli, Mayer (2005) Economie internationale, Dalloz.
- Picard (1992) Eléments de microéconomie, Montchrestien.
- Stiglitz (2000) Principes d'économie moderne, De Boeck Université.

Resources

Teaching team led by **Pascal da Costa**.

Lectures in French or English (maximum 200 students in English).
"Integrated classes" (in French only) are also open (i.e., courses and tutorials in the same class, for about 70 students in each classroom).

NB: English and French Lectures are organized as follows: 1.5 hour face-to-face course, followed by a 1.5 hour face-to-face tutorial.

Learning outcomes covered on the course

- know recent economic theories, their purpose and their limits;
- know the processes to generate knowledge in economic analysis, in the fields of competition, growth financing, currency, economic policies and international trade, sustainable development;
- develop and implement simple mathematical models in micro and macroeconomics;
- write an essay in economics

Description of the skills acquired at the end of the course

C3.1 Observe and allow to criticise the world as it is, doubt, go beyond injunctions, question one's initial assumptions, allow oneself to learn from one's failures, diagnose

C4.1 Identify and (re)formulate the client's need for value creation and the associated issues and constraints. Identify and integrate other internal and external stakeholders and other dimensions not initially mentioned (technical, economic, human, etc.)

C5.3 Analyse global and/or local international issues and adapt projects or solutions to them

C9.2 Analyse and anticipate the possible consequences of the organisations and economic models of the structures to which one contributes

2SL1100 – Climate science and climate change issues

Instructors : **Didier Paillard**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **long semester course**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE METZ, CAMPUS DE RENNES**
Workload (HEE) : **30**
On-site hours (HPE) : **21,00**

Description

The objective of the "Climate Sciences" course is to provide the scientific basis for understanding the issues and challenges of current climate change. A first step is to situate the current transition in the more general context of climate changes that already occured in the past. Indeed, it is only through the evocation of these past crises that we can draw a picture of the various consequences of the current crisis (climate, sea level, acidification, ecosystem changes, etc.). In addition, it is necessary to present the main physical principles which determine climate, in particular the planet's radiation balance and its geographical and seasonal variations, but also the basic ingredients of the greenhouse effect, in particular the carbon cycle which modifies and regulates climate on various time scales.
Beyond these general points, the objective of the course is also to present the modeling tools that are used today, both to better understand and quantify the processes involved, but also to simulate possible future climates. For this, it is important to specify what is the physical and geochemical content of these models by detailing the respective role of the conservation equations and that of the parametrizations. In the end, as there is no perfect tool integrating all the processes, it is necessary to establish various modeling strategies to answer different scientific or societal questions.

Quarter number

ST5

Prerequisites (in terms of CS courses)

No prerequisites.

Syllabus

- observation of natural climate variability and its phenomenology: forcings, feedbacks, threshold effects, flip-flops, and hysteresis.
- the main physical and chemical principles: the greenhouse effect (radiation), energy and water transport (balance equations, heat transfer, thermodynamics), the carbon cycle.
- numerical simulations of the climate.
- anthropogenic impact factors: greenhouse gas emissions, aerosols, land use, and future scenarios.

Class components (lecture, labs, etc.)

Lectures: 7h30

Tutorials: 4h30
Conference: 2h00
Exam: 1h00

Grading

Online Quiz (mandatory)

Course support, bibliography

1. Course slideshow
2. About climate change: the IPCC reports (including "summaries for policymakers") from groups 1 ("climat": https://www.ipcc.ch/report/ar6/wg1/), 2 ("impacts": https://www.ipcc.ch/report/ar6/wg2/) and 3 ("mitigation/adaptation": https://www.ipcc.ch/report/ar6/wg3/). The synthesis report 2023 (https://www.ipcc.ch/report/sixth-assessment-report-cycle/)
3. About climate and related research: see the IPSL links: https://www.ipsl.fr/Pour-tous

Resources

Responsible of the course: Didier Paillard.
Teaching Team (LSCE): Masa Kageyama, Didier Paillard.

Lectures in French or in English
Tutorials in French or in English.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- anchor the questions relating to climate change currently under way in the familiar physical principles of engineering (thermodynamics; mass, energy and momentum balance,...).
- understand the orders of magnitude for energy, the natural carbon cycle and their anthropogenic disturbances.
- implement the notions of feedback, threshold, hysteresis, complex system, in the context of the functioning of planet Earth.

Description of the skills acquired at the end of the course

C1.1 Examine a problem in full breadth and depth, within and beyond its immediate parameters, thus understanding it as a whole. This whole weaves the scientific, economic and social dimensions of the problem.
C2.1 Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.
C2.2 Import knowledge from other scientific fields or disciplines
C9.4 Demonstrate rigour and critical thinking in approaching problems from all angles, scientific, human and economic.

2SL2000 – Law

Instructors : **Valérie Feray**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **ENGLISH, FRENCH**
Type of course : **long semester course**
Campus : **CAMPUS DE METZ, CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES**
Workload (HEE) : **20**
On-site hours (HPE) : **10,00**

Description

- General introduction to law and its role in society
- Contract law, civil liability
- Fundamentals of Intellectual Property Law (patents, trademarks, designs, copyright for software protection)

Quarter number

ST5

Prerequisites (in terms of CS courses)

None

Syllabus

Topics of the lectures :

1. Introduction to law
2. Contract law, civil liability
3. Patent, trademark and design law
4. Software protection

Class components (lecture, labs, etc.)

Lectures (3*1:30) | Tutorials (3*1:30) | Final Exam (1*1:00)

Grading

Final exam (100% of final mark): Multiple choice questions without documents

Course support, bibliography

Ø *Traité de droit de la Propriété Industrielle, Tomes 1 et 2. Jérôme Passa*

Resources

Teaching staff :

• Valérie FERAY : main lecturer - Founder and managing partner - Patent Attorney | IPSILON

• Grégoire DESROUSSEAUX : speaker and teaching assistant - Attorney-at-law & Partner | August & Debouzy

Learning outcomes covered on the course

Have a legal basis in the fundamental law aspects which the engineers and entrepreneurs can face, in order to give them good reflex in sensitive situations

Description of the skills acquired at the end of the course

C 1.1 - Examine a problem in full breadth and depth, within and beyond its immediate parameters, thus understanding it as a whole. This whole weaves the scientific, economic and social dimensions of the problem.
C.2.3 - Rapidly identify and acquire the new knowledg and skills necessary in applicable domains, be they technical, economic or others.
C 3.1 - Be proactive and involved.
C 4.1 - Think in client terms, identify and analyse customer needs, the constraints of other stakeholders as well as include societal challenges.
C 9.4 - Demonstrate rigour and critical thinking in approaching problems from all angles, be they scientific, social or economic.

2SL3000 – Philosophy

Instructors : **Cynthia Colmellere**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **ENGLISH, FRENCH**
Type of course : **long semester course**
Campus : **CAMPUS DE METZ, CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES**
Workload (HEE) : **30**
On-site hours (HPE) : **16,50**

Description

This course is an introduction to philosophy. It is structured around different branches of philosophy, in particular moral and political philosophy and the philosophy of science.
This teaching has four objectives.
1. Introduce the discipline through its history, the major questions it addresses and the types of answers it offers,
2. Understand and question the scientific approach based on knowledge in the philosophy of science and epistemology,
3. Initiate and deepen a reflection on scientific and technological progress with social progress.
4. Based on fundamentals in moral and political philosophy, propose resources for reflection on professional (engineering ethics) and personal ethics.

The examples and situations are taken from different fields related to the social issues covered in the curriculum from the first year onwards. These examples could be linked to scientific, technological, political and social news. This variety of situations, and contexts is intended to facilitate the understanding and use of the concepts studied. Each part includes a theoretical basis and developments based on examples from the history of science and technology and political and social history.
Main concepts covered

1. Truth, scientific evidence
2. Knowledge, ignorance
3. Technological progress/social progress
4. Power, democracy, responsibility
5. Ethics

Quarter number

ST7

Prerequisites (in terms of CS courses)

none

Syllabus

- Each class session lasts 1h30, the sessions are grouped into 3h sessions

Class components (lecture, labs, etc.)

This course takes the form of conferences.

Grading

The evaluation is an individual work (essay), duration: 3H

Course support, bibliography

Each speaker will send a bibliography relating to his or her part of the course.

Resources

Specialists give the courses in the form of conferences:

Gif: M. Girel et M. Klein
Rennes : M. Calori, Mme Gueguen
Metz Mme Aubert

- Please note that the course content and examination subjects differ from one campus to another.

Description of the skills acquired at the end of the course

- Understand situations of innovation, uncertainty, controversy, crisis, economic and technological change using a critical analysis of scientific knowledge.
- Identify, in these situations, the normative frameworks, the worldviews, the economic, ethical, and societal stakes of the different actors concerned (collaborators, citizens, scientists, or institutions), and consequently their respective positions.
- Associate in one's analyses, decisions, and actions, technical, scientific and human, and social sciences knowledge.

2SL4000 – Sociology of organizations

Instructors : **Cynthia Colmellere**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **long semester course**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES, CAMPUS DE METZ**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

This course is an introduction to the sociology of organizations. This part of sociology studies individual and collective behaviors within constituted human groups: organizations.
This course provides theoretical and methodological knowledge in organizational sociology and psychosociology for use in real contexts of problem-solving and change. This course covers the main phenomena in organizations: decisions, strategies, power, negotiations, conflict... It also helps to understand dysfunctions and deviance phenomena in organizations. A typology of the forms and modes of functioning of organizations allows students to address some common problem situations.

Quarter number

SG6

Prerequisites (in terms of CS courses)

Economic, business administration, business games

Syllabus

This course in the sociology of organizations deals with the following notions:
- Introduction to sociology (concepts, methods, foundations, scientificity).
- The notions of organization, institution, organized group.
- The founding works of the sociology of organizations: F. W Taylor (doctrine, scientific organization of work (OST); H. Ford (Fordism), Toyotism
- The doctrines of work organization, the rationalization of work, from the industrial revolution to the most recent developments of capitalism (dematerialization of work, platforms),
- The notion of work

Each notion is approached from a theoretical point of view and examples (situations, surveys) in various formats.

- Norms and rules in organizations, compliance, adaptations, deviance
- The bureaucratization of organizations

- Notions of power, authority, legitimacy, domination.
- Introduction and practice of strategic and systemic analysis of organizations
- Criticisms of the strategic analysis of organizations and proposals: new approaches to analyze human and social dynamics in organizations.

Class components (lecture, labs, etc.)

This teaching consists of courses and TDs. It combines theoretical contributions, exercises, case studies, simulations... Examples and practical cases are taken from different fields: companies and industries, institutions (political, educational), associations. This variety of situations and contexts is intended to facilitate the implementation of the proposed concepts and methods.

The course is given in French but reference texts (from a textbook) are given in English.
A Td is offered in English in its entirety on the Gif campus,

On the Rennes and Metz campuses, one of the two Td's is given in French but the interaction with the teacher can be in English.

Grading

The proposed evaluation methods are: An individual evaluation: 3-hour table-top exam, without documents, course questions, and case study. 100 % final score

Course support, bibliography

Amblard, H., Bernoux, P., Herreros, G., Livian, Y.-F., Les nouvelles approches de la sociologie des organisations, Paris, Seuil, 2007 (3ème édition augmentée).
Ballé C., La sociologie des organisations, Bidet, A., Borzeix, A. Pillon, T., Rot, G. et F. Vatin (coordinateurs) (2006). Sociologie du travail et activité, Toulouse : Octarès Editions, 2006.
Chamayou G. La société ingouvernable. Une généalogie du libéralisme autoritaire, Paris, La Fabrique, 2018
Crozier M., Le phénomène bureaucratique, Paris, Seuil, 1963
Crozier M., Friedberg E., L'acteur et le système, Paris, Seuil, 1977.
Graeber, D. Bureaucratie. L'utopie des règles, Paris, Les Liens qui libèrent, 2015,
Hely, M., Moulevrier, P., L'économie sociale et solidaire, de l'utopie aux pratiques, Paris, La Dispute, 2013.
Linhart, R. L'établi, Paris, Editions de minuit, 1978.
Seris, J.-P., Qu'est-ce que la division du travail, Paris, Vrin, 1994.
Stroobants, M., Sociologie du travail, Paris, Amand Colin, 2010 (3ème édition).
Terkel S., Working, Histoires orales du travail aux Etats-Unis, Paris, Editions Amsterdam, 2005 (1st Edition 1972, 1974)
Weber M., L'Éthique protestante et l'esprit du capitalisme, Paris, Plon, 1964.
Weber M., Économie et Société, Paris, Plon, 1971
Weber M., La domination, Paris, La Découverte, coll. « Politique & sociétés », 2013, édition critique française établie par Yves Sintomer, traduction française par Isabelle Kalinowski

Resources

- Teaching team (names of the teachers of the lectures): Cynthia Colmellere (Gif), Natacha Chetcuti Osorovitz (Rennes et Metz)
- Size of the TDs (default 35 students): 40

Learning outcomes covered on the course

- Acquire methods and practices of reasoning to explain behaviors in reference to interests, strategies, values, and experiences
- Acquire a way of thinking about problems in organizations that avoids explanations limited to personality or individual psychological characteristics.
- Understand failures and successes in change processes in organizations.
- Understand the systemic complexity in organizations (companies, institutions, administrations) by taking into account the human and social dimensions and the context.
- Understand the strength of the logic of actors at the individual and collective level

Description of the skills acquired at the end of the course

- analysing problems in organizations avoiding explanations limited to personality or individual psychological characteristics.
- analysing failures and successes in change processes in organizations.

2SL5007 – "Engineering Skills" Workshops - 2A

Instructors : **Christophe Laux**
Department : **DÉPARTEMENT DÉVELOPPEMENT PROFESSIONNEL ET MÉTIERS DE L'INGÉNIEUR**
Language of instruction : **FRENCH**
Type of course : **semester long course**
Campus : **CAMPUS DE METZ, CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **18,00**

Description

This course is the continuation of 1SL5000. The objective is to continue exploring and developing the skills expected from a CentraleSupelec engineer: teamwork, project management, communication, complex problem solving, creativity, leadership, ethics, multicultural awareness.

Quarter number

ST5, SG6, ST7 and SG8

Prerequisites (in terms of CS courses)

Semester S7: participate in the S7 project

Semester S8: participate in the S8 project

Syllabus

Key skills of the engineer:
- teamwork: organize, decide, lead in a team; different roles of team members; influence of the personality on the performance of the team
- oral communication: develop impactful oral communication, speak in public, structure a synthesis, build a presentation
- approach to solving complex problems:analyze the issues, make robust assumtions, use relevant orders of magnitude, manage risk and uncertainty
- creativity: understand group creativity methods
- leadership and self-knowledge
- multicultural: open to others, understand how to adjust to a different environment
- ethics: act ethically, understand the consequences of one's choices

API 8: Project coaching
API 9: Energy transition day
API 10: Leadership
API 11: Ethics
API 12: Project Coaching
API 13: Project Coaching

Class components (lecture, labs, etc.)

- Case studies in groups
- Practical applications
- Application of the skills seen in the workshops to a real project
- Homework

Grading

Attendance at the workshops is mandatory because any absence penalizes the learning of the student and handicaps the group.

The participation of each student during the workshops is graded because it is a necessary condition for learning skills.
Individual or team work requested during workshops or between workshops is graded. The respect of the deadlines intervenes in the evaluation.
The team work gives rise to a collective grade for the team (except in the obvious case of withdrawal of the team).
The individual essays are given full credit if they are turned in on time and show sufficient quality of the personal reflection, without judgment on the opinions expressed when they are argumented.
Mini-quizzes may be given at the beginning of some of the workshop, on the content of previous workshops,. The quizzes are then graded.

The grade of each semester will be based on:
- Productions in the group work
- Individual and team homework (TIA)
- Quality of individual participation
- Result of the mini-quizz if any

An unjustified absence (ABI) leads to a penalty of 2 points per half-day of absence

At the end of each semester, validation of skills C3, C4, C7, C8 and C9 (pass/fail)

Resources

Workshops in groups of 30 to 40 students, led by two professors

Practical engineering cases
Films and videos
Exchanges with other students and invited professionals
Conferences
Close link between the workshops and the second year team project of S8

Learning outcomes covered on the course

At the end of this course, the student will have understood the basics of:

- teamwork
- communication
- problem solving
- creativity techniques
- leadership
- working in a multicultural environment
- ethics in engineering

Description of the skills acquired at the end of the course

At the end of the course, the student will have continued to progress in the following skills:
- solving complex problems (C1)
- be proactive, take initiatives, propose new solutions (C3)
- think customer and know how to identify the value brought (C4)
- familiarization with intercultural (C5)
- know how to convince (C7)
- lead a project and work in a team (C8)
- act ethically (C9)

2SL7007 – Professional Practice Workshops - 2A

Instructors : **Christophe Laux**
Department : **DÉPARTEMENT DÉVELOPPEMENT PROFESSIONNEL ET MÉTIERS DE L'INGÉNIEUR**
Language of instruction : **FRENCH**
Type of course : **long semester course**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE METZ, CAMPUS DE RENNES**
Workload (HEE) : **20**
On-site hours (HPE) : **6,00**

Description

This course aims to continue supporting students in the discovery of the engineering profession and in the construction of their professional project

Quarter number

ST5, SG6, ST7, and SG8

Prerequisites (in terms of CS courses)

None

Syllabus

This course includes:
- a 3-hr workshop to share experiences on the blue-collar internship or similar experiences, and to learn about résumés, motivation letters and pitches
- a 1.5 hr workshop to train for recruiting interviews (internships, gap year, …)
- two individual exchanges with one of the professors
- two round tables with company representatives

Class components (lecture, labs, etc.)

- group work
- experience sharing and report on the blue-collar internship
- one-on-one meetings with one of the professors
- exchanges with company representatives

Grading

Active attendance at the workshops and one-on-one meetings is mandatory.

The course is graded as "pass or fail".
To receive a passing grade for the APPs of semester 7, the following conditions must be all met:
- attend the collective workshops,
- prepare and attend the one-on-one meeting
- attend 2 round tables

To receive a passing grade for the APPs of semester 8, it is required to prepare and attend the one-on-one meeting and to participate actively in the “Simulation of recruiting interviews” workshop
A final report on the professional project may be required.

Resources

Workshops in groups of 30 to 40 students, led by two professors

2SL8000 – Project S7

Instructors : **Laurent Bourgois**
Department : **DÉPARTEMENT DÉVELOPPEMENT PROFESSIONNEL ET MÉTIERS DE L'INGÉNIEUR**
Language of instruction : **ENGLISH, FRENCH**
Type of course : **long semester course**
Campus : **CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY, CAMPUS DE METZ**
Workload (HEE) : **90**
On-site hours (HPE) : **48,00**

Description

A project is a collective work modality used to apprehend complex open problems. Its effectiveness depends on the individual skills of each person and on the team's operating practices; the objective being to produce a final product for a sponsor in a given time. The projects proposed in the engineering training program allow the learning of this modality through increasingly complex situations. The objective of this activity is to collectively implement the different stages of a project, from the definition of the need to the delivery of the product, in order to produce a deliverable for a client. The projects must lead to an ambitious realization, which could not be reached by redoing what we already know how to do.

Quarter number

ST5 and SG6

Prerequisites (in terms of CS courses)

Project management, API workshops.

Syllabus

The projects are spread over two sequences (ST5 and SG6). They follow the usual phases of a project:
- Define and frame the project.
- Structure the actions.
- Define roles and responsibilities.
- Measuring progress and completing actions.
- Increase technical and organizational skills.
- Communicate your achievements.
- Capitalize on acquired experience.

Class components (lecture, labs, etc.)

The progress of the project is accompanied by numerous and varied interactions with the project environment. It is based on individual and collective actions. We will find :
- collective times at the level of the pole for the transmission of good practices and knowledge ;
- personal work to be defined within the group;
- collective work to align and steer the project group.

The supervisors will monitor the project regularly to ensure that no blockages occur and to validate the steps taken.

Grading

The evaluation will focus on ongoing participation during the year, the quality of the written report and the oral presentations made during the project. These contributions will be looked at from four different angles: involvement, content and deliverables, communication, and team functioning in project mode. A validated project implies that the student has validated at least 2 out of 3 competencies from the set {C4, C7, C8}.

Resources

The projects are carried out by groups of 5 students. Each project is attached to a cluster where projects of the same nature are grouped together. The clusters provide supervision and software and hardware resources. Except in exceptional cases, students remain assigned to the project cluster in which they were in semester S6. They can continue to work on the same subject or start a new project in agreement with the people in charge of the pole. There is no online assignment campaign. Students who were not attached to a project group in semester S6 can ask to join a group. They will be able to complete existing teams or initiate a new project.

Learning outcomes covered on the course

By the end of this course, students will be able to:

- interact with a client remotely and face-to-face (telephone discussion, email exchange, oral presentation, conduct a progress meeting, etc.);
- identify the value of their work in solving a complex problem;
- organize a team to produce an original and valuable solution;
- anticipate the human, social and environmental consequences of one's actions, and determine the scope of one's responsibilities;
- present a scientific work in writing and orally (in particular, good management of bibliographic resources and clear and rigorous communication of achievements);
- produce a high value-added deliverable in relation to various stakeholders.

Description of the skills acquired at the end of the course

In general, a successful project is one where students have:

- Properly posed the problem and provided solutions that create value (there is a before and after project for the client) ;
- brought a minimum of innovation or creativity to respond to the problem in an innovative way;
- knew how to work as a team and manage the project with resources;
- were convincing in their oral or written communication;
- were able to take a step back from the ethical aspects.

Throughout the project, we find the following skills:

- C3: Act, undertake, innovate in a scientific and technological environment.
- C4 : To have a sense of creating value for one's company and one's clients.
- C7 : Know how to convince.
- C8 : Lead a project, a team.
- C9 : Think and act as an ethical, responsible and honest engineer, taking into account environmental, social and societal dimensions.

Depending on the nature of the project, skills C1, C2, C5 and/or C6 may also be targeted.

2SL8100 – Project S8

Instructors : **Laurent Bourgois**
Department : **DÉPARTEMENT DÉVELOPPEMENT PROFESSIONNEL ET MÉTIERS DE L'INGÉNIEUR**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **long semester course**
Campus : **CAMPUS DE METZ, CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **200**
On-site hours (HPE) : **108,00**

Description

A project is a collective work modality used to apprehend complex open problems. Its effectiveness depends on the individual skills of each person and on the team's operating practices; the objective being to produce a final product for a sponsor in a given time. The projects proposed in the engineering training program allow the learning of this modality through increasingly complex situations. The objective of this activity is to collectively implement the different stages of a project, from the definition of the need to the delivery of the product, in order to produce a deliverable for a client. The projects must lead to an ambitious realization, which could not be reached by redoing what we already know how to do.

Quarter number

ST7 and SG8

Prerequisites (in terms of CS courses)

Project management, API workshops.

Syllabus

The projects are spread over two sequences (ST7 and SG8). They follow the usual phases of a project:
- Define and frame the project.
- Structure the actions.
- Define roles and responsibilities.
- Measuring progress and completing actions.
- Increase technical and organizational skills.
- Communicate your achievements.
- Capitalize on acquired experience.

Class components (lecture, labs, etc.)

The progress of the project is accompanied by numerous and varied interactions with the project environment. It is based on individual and collective actions. We will find :
- collective times at the level of the pole for the transmission of good practices and knowledge ;
- personal work to be defined within the group;
- collective work to align and steer the project group.

The supervisors will monitor the project regularly to ensure that no blockages occur and to validate the steps taken.

Grading

The evaluation will focus on ongoing participation during the year, the quality of the written report and the oral presentations made during the project. These contributions will be looked at from four different angles: involvement, content and deliverables, communication, and team functioning in project mode. A validated project implies that the student has validated at least 2 out of 3 competencies from the set {C4, C7, C8}.

Resources

The projects are carried out by groups of 5 students. Each project is attached to a cluster where projects of the same nature are grouped together. The clusters provide supervision and software and hardware resources. At the beginning of the year, the clusters are presented at a forum. Students can ask to join a cluster. They can also propose to carry out a personal project with a team that will be hosted in a cluster. All students participate in an online assignment campaign. Pole leaders help select the most motivated students. Students who wish to remain in the pole in which they were in the S7 semester are given priority but will still have to go through the assignment campaign.

Learning outcomes covered on the course

By the end of this course, students will be able to:
- interact with a client remotely and face-to-face (telephone discussion, email exchange, oral presentation, conduct a progress meeting, etc.);
- identify the value of their work in solving a complex problem;
- organize a team to produce an original and valuable solution;
- anticipate the human, social and environmental consequences of one's actions, and determine the scope of one's responsibilities;
- present a scientific work in writing and orally (in particular, good management of bibliographic resources and clear and rigorous communication of achievements);
- produce a high value-added deliverable in relation to various stakeholders.

Description of the skills acquired at the end of the course

In general, a successful project is one where students have:
- Properly posed the problem and provided solutions that create value (there is a before and after project for the client) ;
- brought a minimum of innovation or creativity to respond to the problem in an innovative way;
- knew how to work as a team and manage the project with resources;
- were convincing in their oral or written communication;
- were able to take a step back from the ethical aspects.

Throughout the project, we find the following skills:
- C3: Act, undertake, innovate in a scientific and technological environment.
- C4 : To have a sense of creating value for one's company and one's clients.
- C7 : Know how to convince.
- C8 : Lead a project, a team.
- C9 : Think and act as an ethical, responsible and honest engineer, taking into account environmental, social and societal dimensions.

Depending on the nature of the project, skills C1, C2, C5 and/or C6 may also be targeted.

2SL9000 – Sport

Instructors : **Stéphane Blondel**
Department : **DÉPARTEMENT EDUCATION PHYSIQUE ET SPORTIVE**
Language of instruction :
Type of course : **long semester course**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES, CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **48,00**

Description

1. To contribute, through the practice of physical sports activities and expression , to the training of future citizens.

Quarter number

S7 and S8

Prerequisites (in terms of CS courses)

none

Grading

In-service training Self-assessment

Learning outcomes covered on the course

- Managing the risk/safety pair
- Integrate an "eco-citizen" approach
- Use a collective project methodology.
- Take responsibility within a group, a team, an association.
- Be able to communicate and listen.
- Demonstrate innovation and creativity
- To enter into a logic of personal development
- To train throughout one's life

Description of the skills acquired at the end of the course

1-
Distinguish between situations of perceived (subjective) risk and situations of real (objective) risk to self and others (C3-4, C9-1, C9-2, C9-3, C9-4)

Master attitudes that ensure individual and collective safety (C3-4, C9-1, C9-2, C9-3, C9-4)

Manage emotions in situations of opposition, competition, representation or uncertainty (C3-4, C7-3, C9-1, C9-2, C9-3, C9-4)

2-

Act with respect for oneself and others - take into account differences (disability, cultures...) (C3-4, C3-7, C5-2, C7-2, C7-3, C9-1, C9-2, C9-3, C9-4)

Respect the environment, practice areas and equipment (C3-4, C7-3, C9-1, C9-2, C9-3, C9-4)

Show empathy and altruism (C3-4, C7-3, C9-1, C9-2, C9-3, C9-4)

3-

Define achievable common goals (C8-1, C8-2, C8-3, C8-4)

Define and allocate roles within the group (C3-2, C7-2, C7-3, C8-1, C8-2, C8-3, C8-4)

Make and accept decisions (C3-2, C8-1, C8-2, C8-3, C8-4)

Regulate and follow up a group project (C3-2, C8-1, C8-2, C8-3, C8-4)

4-

Accept roles and assume responsibilities related to missions (including financial) (C8-1, C8-2, C8-3, C8-4)

Use levers to motivate a team or an individual (C8-1, C8-2, C8-3, C8-4)

Train peers (C8-1, C8-2, C8-3, C8-4)

5-

Adapt communication to the group, to the individual, to non-specialists... (C8-1, C8-2, C8-3, C8-4)

Use verbal and non-verbal communication (C8-1, C8-2, C8-3, C8-4)

Manage conflict (C8-1, C8-2, C8-3, C8-4)

Make appropriate use of ICT (information and communication technology) (C8-1, C8-2, C8-3, C8-4)

6-

Imagine original solutions (C3-1, C3-4, C3-7, C8-2)

Dare to leave one's comfort zone (C3-1, C3-4, C3-7, C8-2)

Engage in a creative process (C3-1, C3-4, C3-7, C8-2, C8-3)

7-

Adapt warm-up and training to your profile (C2-2, C2-3, C9-1)

Know your strengths and weaknesses (C2-2, C2-3, C9-1)

8-

Question oneself in order to evolve in one's practices (C2-2, C2-3, C9-1)

Plan your practice with a view to an objective (C2-2, C2-3, C9-1)

SCIENCE COURSES FOR ENGINEERS

2EL0010 – Teaching assistant

Instructors : **Mehdi Ayouz, Philippe Bouafia**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **Yes**

Description

Teaching Assistant Physics: this course consists of tutoring and supporting first year students in their Quantum and Statistical Physics course. It is a great opportunity to learn about teaching for a potential teaching career or to apply for Teaching Assistant positions in famous North American universities. The objective is that you learn how to (i) pass on your knowledge and understanding to a non-expert audience, and (ii) accompany a student in his or her progress towards a validation of knowledge and understanding of the Quantum Mechanics course.

Quarter number

SG6 and SG8

Prerequisites (in terms of CS courses)

Good level in quantum and statistical physics as well as in mathematics (CIP and EDP)

Syllabus

Teaching Assistant for Physics: an introductory course will give the necessary elements for the construction of teaching objectives, the construction of qcms and the notions of scripting and pedagogical alignment. However, the majority of this course is do-it-yourself. You will be paired with a group of about 15 first year students with potential difficulties as they come from non-classical backgrounds. There will be nine 1h30 sessions, each session focusing on a chapter of the Quantum and Statistical Mechanics course. For each session, a pair of students will carry out the "reinforcement" tutorials developed for this purpose. The pair will participate in upgrading the tutorials based on feedback from previous year by defining the pedagogical learning objectives. They will realize a qcm for testing these pedagogical objectives. The 1h30 session will be dedicated to the correction of reinforcement tutorials with their assigned group. They will be asked to focus on the points of difficulty encountered to help the progression of the 1st year students.

Class components (lecture, labs, etc.)

Teaching Assistant in Physics: Introductory course and simulation (pair ensuring 9 classes of 1h30 with a total of 15 first year students, upgrade the existing tutorials, design of qcm).
Teaching Assistant in Mathematics: Pairs or trinomials of Teaching Assistants will supervise about ten first year students throughout the year and will have a referent teacher to guide them in this activity. Each Enhanced Modality session will be preceded by a briefing with the teacher, the TAs will propose their plan for the session in a summary sheet, and a debriefing will take place after the session.

Please note: it is not possible to be a Teaching Assistant in Physics AND Maths, but only in one or the other.

Grading

Teaching assistant in Physics: you will be assessed in pairs on your contribution to tutorials, qcm constructed and on the animation of a lesson.

Learning outcomes covered on the course

Teaching Assistant Physics: at the end of this course, students will be able to (1) set up a grid of pedagogical objectives, (2) create a qcm type assessment adapted to the pedagogical learning objectives, and (3) script and lead a session in front of a class of about fifteen students, and use digital tools (in particular the teaching platform: http://prd-mecaqu.centralesupelec.fr/) allowing the student-user to carry out his own numerical experiments in order to better represent the core concepts of quantum mechanics. Pedagogical and supervisory skills and persuasive skills are also acquired skills targeted by this course (C5.1, C7.2, C7.3 and C7.4).

Teaching Assistant in Mathematics: Pedagogical, supervisory and persuasive skills (C5.1, C7.2, C7.3 and C7.4)

2EL1110 – Dynamical systems in neuroscience

Instructors : **Antoine Chaillet**
Department : **DÉPARTEMENT AUTOMATIQUE**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

This course constitutes an introduction to tools for the analysis of dynamical processes involved in brain functioning. Despite their huge complexity, brain functions are indeed based on elementary dynamics, some of which can be apprehended by a mathematical approach. Mastering these techniques is fundamental to progress in our understanding of brain functioning, to optimize instrumentation for brain activity measurements (brain imaging, electrophysiological recordings…), to improve brain-machine interfaces, to build up neuro-inspired computational units, and to understand the mechanisms involved in some brain diseases and thus improve their treatment.

Quarter number

SG6

Prerequisites (in terms of CS courses)

- SG1 : Information systems and programming
- SG1-ST2-SG3 : Convergence, integration, probability, partial differential equations
- ST2 : Modelling
- ST4 : Signal processing
- ST5 : Control theory

Syllabus

Chapter 1: Fundamentals in physiology and brain functions (CM: 4,5h)
This first chapter introduces the physiological bases of neuronal activity. It describes the elementary principles involved in the generation of an action potential and in the communication between neurons (soma, axon, dendrite, synapse, ion channels, rest potential), as well as synaptic plasticity and homeostatic regulation mechanisms. It describes the physical and biological principles that come into play in these behaviors. It finally presents the main brain functions (memory, motor tasks, olfaction, and vision) and their alteration in pathological conditions.

Chapter 2: Measurement and actuation of brain activity (CM: 3h)
This second chapter presents different techniques to measure brain activity, including electrophysiological techniques (patch-clamp, multi-unit recordings, LFP, EEG, MEG) and brain imaging (MRI, 2-photon). It also describes technological ways to influence brain activity, including electrical stimulation and optogenetics.

Chapter 3: Brain-machine interfaces (CM: 4.5h)
This sixth chapter addresses the development of brain-machine interfaces, also known as neuroprostheses. These devices aim at restoring the autonomy of amputated or quadriplegic patients. Their implementation in animals or humans also provides knowledge on the functioning and learning of natural sensory-motor loops. This chapter details the needed elements for such interfaces: neuronal activity recording (whether invasive or not),

signal processing, motor control, and sensory feedback from the prosthesis to the brain. It also describes the plasticity mechanisms on which these interfaces can rely to optimize learning.

Chapter 4: Mathematical models of neurons (CM: 3h)
This chapter presents well-known neuron models. It introduces conductance-based models through the famous Hodgkin-Huxley model and underlines its electronic analogy. It then presents simplified models, such as integrate & fire or FitzHug-Nagumo models, as well as simple models of synapses and neuronal plasticity. Numerical simulation of these models is also introduced.

Chapter 5: Analysis of neuron models (CM: 6h, TP: 3h)
This chapter present mathematical tools to study neuronal behavior. It introduces the notion of phase diagram and bifurcation. These notions are first given for one-dimensional systems, and then for planar systems. The chapter establishes a link between these bifurcations and the qualitative behavior of the neuron. A lab session on Matlab-Simulink aims at implementing a conductance-based model of a neuron and to predict its response thanks to the introduced theoretical tools.

Chapter 6: Neuronal populations (CM: 3h,)
This chapter addresses the dynamics of a whole population of neurons or a cerebral structure. It presents simplified models of the activity of a population, such as the Wilson-Cowan model or neural fields. It shows how to predict the behavior of such models by stability or bifurcation analysis. A lab session on Matlab-Simulink will aim at studying the binocular rivalry phenomenon through a simple neuronal population model.

Conference: Example of a start-up creation (1.5h)
A conference by the co-funder and scientific manager of start-up Dreem (Rhythm) concludes this course by presenting recent industrial innovations (non-invasive measurement of brain activity, pattern recognition in electrophysiological data, …) as well as opportunities given by neuroscience for industry and entrepreneurship.

Class components (lecture, labs, etc.)

CM, TD, TP, homework.

Grading

Evaluation will be made based on a written exam without documents (2h) at the end of the course and on the written reports of the two lab sessions. The following weights are envisioned: 60% for the written exam and 20% for each lab session report. Any unjustified absence at the TP will lead to a zero as TP grade. Skills will be evaluated through the lab session reports and the written exam. Skills C1.2 and C1.3 will be deepened during the lab sessions.

Course support, bibliography

- Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting, Eugene M. Izhikevich, The MIT Press, 2007
- Nonlinear dynamics and Chaos, by Steven Strogatz, Westview Press, 2001
- Mathematical Foundations of Neuroscience, by G. Bard Ermentrout & D. Terman, Springer, 2010
- Theoretical neuroscience, by P. Dayan & L.F. Abbott, The MIT Press, 2005

Resources

A multi-disciplinary teaching team, including researchers in computational neuroscience, a neurosurgeon, a professor in control theory and a start-up creator.

Practical works will be made on computers with Matlab-Simulink.

Learning outcomes covered on the course

At the end of this course, students will have acquired basic neuroscience knowledge to allow interaction with professionals of the field (neurosurgeons, computational neuroscientists, experimenters). They will know of mathematical tools to model activity of a single neuron or a whole neuronal population, and to predict their dynamical properties both analytically and through simulations. They will also have been made aware of opportunities offered by neuroscience in terms of research, medical and industrial development, and entrepreneurship.

Description of the skills acquired at the end of the course

By the end of this course, students will be able to:

1. Understand neuroscience fundamentals, for possible interaction with professionals of the field (neurosurgeons, computational neuroscientists, experimenters)
2. Model the activity of a neuron or a whole neuronal population
3. Predict their behavior both analytically and numerically.

This course will thus be an opportunity to deepen skills:

- C1.2: "Use and develop adequate models, choose the right modeling scale and the right simplifying assumptions to treat a problem": Jalon 3
- C1.3: "Solve a problem by employing approximation, simulation and experiments": Jalon 2A
- C1.5: "Use a wide scientific and technical background in the context of a transdisciplinary approach"
- C2.2: "Transpose to other fields, generalize knowledge"
- C2.3: "Quickly identify and acquire new knowledge and skills in relevant domains (technical, economical or other)".

2EL1120 – Interactive Robotic Systems

Instructors : **Maria Makarova**
Department : **DÉPARTEMENT AUTOMATIQUE**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

Industrial and service robotics currently undergo deep changes with the development of **collaborative robots designed to interact physically with humans**, and to share the same workspace or the same task. Collaborative robots are key elements both in **factories of the future** or in **assistance** tasks. Human-robot interaction is therefore an active research and development domain in robotics. It requires a **multidisciplinary** approach to design safe and efficient advanced systems.

Subjects covered by this course will allow the students to understand the main issues of interactive robotics and the scientific and technical aspects associated to these **complex systems in interaction with humans or their environment**. The course aims at exposing the context, the fundamental methodological tools and the current research and development subjects related to interactive robotic manipulators.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Control Theory (ST5)
Basic knowledge in rigid body mechanics to acquire by self-study if needed

Syllabus

1. Introduction, brief historical perspective, industrial and research context
2. Basics of modeling in robotics (geometric & kinematic models)
3. Dynamic modeling (rigid and elastic body) and control of robots
4. Force-feedback tele-operation
5. Collaborative robotics
6. Introduction to ROS (Robot Operating System)

Class components (lecture, labs, etc.)

Lectures, during which the presented concepts will be abundantly illustrated by examples, will be complemented with tutorial sessions on computers (in groups of two or three) to apply the theoretical concepts on practical case studies. The tutorials will require preparatory personal work outside class.

- **Tutorial #1 and Tutorial #2 :** illustration of robot modeling using Matlab/Simulink or python

- **Tutorial #3 (personal work):** introduction to ROS (Robot Operating Software) and application to robot manipulators

Class components:

- Lectures : 22,5h
- Tutorials on computers : 6h in class
- Final evaluation (quizz) : 2h

Grading

- Tutorials #1 & #2 : Written report following the tutorials with functional and commented programs [50% of overall grade];
- Final evaluation: written quizz with documents (2h) [50% of overall grade].
- Attendance checked during tutorials, possible penalty on the written report grade. An unjustified absence during a tutorial automatically leads to grade 0 for the said tutorial.

Course support, bibliography

- **Handouts :** Slides shown during the lectures
- **References :** W. Khalil, E. Dombre, “Modeling, Identification and Control of Robots”, Butterworth-Heinemann, 2004.

Resources

- **Teaching staff (instructor(s) names):** Mathieu Grossard (CEA LIST Laboratoire de Robotique Interactive), Franck Geffard (CEA LIST Laboratoire de Robotique Interactive), Xavier Lamy (CEA LIST Laboratoire de Robotique Interactive), Alex Caldas (ESME Sudria)

- **Maximum enrollment:** tutorial groups of max 18 students

- **Software**, number of licenses required:

    - Matlab/Simulink, campus license (unlimited)
    - python (free)
    - ROS (free; virtual machine provided with Ubuntu and ROS installed)

Learning outcomes covered on the course

After completion of this course, students will be able to:

1. Describe the current context (through technical, applicative and economic issues) of interactive robotics seen as a multidisciplinary field related to the interaction between human and robot and between robot and environment. Describe the main hardware and software components of an industrial robotic system.
2. Establish the classical models of a robot manipulator: geometric, kinematic, dynamic models.
3. Select the appropriate control architecture depending on the target application and determine its tuning parameters in order to satisfy the performance-robustness trade-off.
4. Model a robot manipulator in contact with a human or a passive environment; determine the stability conditions of the global feedback-controlled system (teleoperation or collaboration cases).
5. Use specialised software (Matlab/Simulink or python, ROS) to build and simulate models of robot manipulators as dynamical systems.
6. Master scientific and technical communication (through reports on the tutorials).

Description of the skills acquired at the end of the course

Evaluated skills: C1, C2, C6

- “Establish the classical models of a robot manipulator: geometric, kinematic, dynamic models” and “Model a robot manipulator in contact with a human or a passive environment” is included in the skill **C1.2 “Select, use and develop modelling scales, allowing for appropriate simplifying hypotheses to be formulated and applied towards tackling a problem” – milestone 2.**
- “Select the appropriate control architecture depending on the target application and determine its tuning parameters in order to satisfy the performance-robustness trade-off” and “determine the stability conditions of the global feedback-controlled system (teleoperation or collaboration cases)” is included in the skill **C1.4 “Design, detail and corroborate a whole or part of a complex system” – milestone 2.**
- “Use specialised software to build and simulate models of robot manipulators as dynamical systems” is included in the skill **C6.1 “Solve a problem numerically”** and **C1.3 "Apply problem-solving through approximation, simulation and experimentation " – milestone 2**
- **C2.1** Deepen your understanding of an engineering or scientific discipline

2EL1130 – Dynamical Multi-Agent Systems. Application to drones formation control

Instructors : **Cristina-Nicoleta Maniu**
Department : **DÉPARTEMENT AUTOMATIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

Numerous applications involve formation of several autonomous systems, capable of cooperation in a specific environment and of reconfiguration for the mission achievement. In particular, formation flying (Unmanned Aerial Vehicles - UAVs, satellites, etc.), car traffic control or pedestrians behavior in a crowd highlight the notion of a dynamic Multi-Agent System (MAS).

In the context of rescue missions (large-scale fire extinguishing missions, search for avalanche victims or black boxes in a large environment, etc.), the coordination and the control of a fleet of autonomous vehicles becomes key elements. These multi-agent missions relay on several MAS concepts such as tasks assignment, trajectory/path planning, and induce control problems in real time under constraints etc. The topics covered in this course will allow students to understand the basic concepts and challenges related to dynamic multi-agent systems via several experimentations on UAVs formations.

Experiments in the flight arena of CentraleSupélec on Crazyflie and DJI RoboMaster TT UAVs, on TurtleBot and DJI RobotMaster S1 ground autonomous vehicles (GAVs), and on the Robotarium remote platform are planned as part of this course.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Control Theory (ST5)

Syllabus

This course is based on a **collaboration with ONERA and the Heudiasyc laboratory** and has the following structure:

- Introduction: a brief history, industrial and academic context;
- Dynamic modeling of multi-agent systems (MAS);
- Specific tools for MAS: notions of vehicles fleet/swarm, communication graph, consensus;
- Modeling and handling of drones and ground vehicles;
- Control techniques of multi-agent systems;
- Taking into account constraints in the cooperative control law;
- Refinement of control laws and analysis of results;
- Multi-agent systems in space missions.

A tutored case study is envisaged as a guideline throughout this course in order to validate the proposed control techniques both in simulation and on an indoor experiment of a fleet of UAVs and/or ground mobile robots.

Experiments are planned in the indoor flight arena of CentraleSupélec.
See experiments en 2022: https://twitter.com/centralesupelec/status/1535211296240685057

Class components (lecture, labs, etc.)

This course is composed of **interactive lectures, tutorials** and a **case study** (*carried out by team on a subject proposed by the students*) that will serve as a guideline throughout this elective module and will lead to indoor experimentations on UAVs formations and mobile robots formations. The case study will follow the progress of the course and will allow acquiring practical skills. Active learning methods such as *Problem-Based Learning (PBL)* in small tutored groups are envisaged for the case studies on UAVs formations.
Students will discover dynamic multi-agent systems through various examples, exercises, discussions, and theoretical and practical guidance. An estimate of the hourly volume (30,5h) is as follows: 13,5h for interactive lectures, 6h for tutorials, 9h for the case study and 2h for the evaluation of interactive posters and peer assessment.

Grading

The evaluation procedure is designed to respect the alignment of objectives - activities - evaluations. A report (containing a state-of-the-art, the analysis of the results obtained during the case study, etc.) will be delivered and evaluated. The results will be presented using an interactive poster in front of a committee and with a cross-examination of the other groups (peer assessment). The final grade is computed from the **report** evaluation **(50%)** and the **interactive poster** evaluation, both poster design and presentation **(50%)**.
A skill-based assement is also envisaged. The **skills C1, C2, C5, C7 and C8** will be assessed.

Course support, bibliography

References

1. *A Massive Open Online Course on Drones and Aerial Multi Robot Systems* (*DroMOOC*), www.onera.fr/dromooc, University Paris-Saclay, 2018.
2. K.K. Oh, M.C. Park, H.S. Ahn, "A survey of multi-agent formation control", *Automatica*, vol. 53, pp. 424-440, 2015.
3. J.A. Guerrero, P. Castillo, S. Salazar, R. Lozano, "*Mini Rotorcraft Flight Formation Control Using Bounded Inputs*", *Journal of Intelligent & Robotic Systems*, vol. 65, pp. 175-186, 2012.
4. J. Guerrero, R. Lozano, "*Flight Formation Control*", John Wiley & Sons, 2012.
5. I. Prodan, "*Commande des systèmes dynamiques Multi-Agents en présence de contraintes*", PhD thesis, Supélec, 2012.
6. M.T. Nguyen, "*Commande prédictive sous contraintes de sécurité pour des systèmes dynamiques Multi-Agents*", PhD thesis, Université Paris-Saclay, 2016.
7. G. Rousseau, C. Stoica Maniu, S. Tebbani, M. Babel, N. Martin, "Quadcopter-performed cinematographic flight plans using minimum jerk trajectories and predictive camera control", *European Control Conference*, Limassol, Cyprus, 12-15 June 2018.
8. Y. Rochefort, H. Piet-Lahanier, S. Bertrand, D. Beauvois, D. Dumur, "Model predictive control of cooperative vehicles using systematic search approach", *Control Engineering Practice*, vol. 32, pp. 204-217, 2014.
9. N. Michel, S. Bertrand, G. Valmorbida, S. Olaru, D. Dumur. "Design and parameter tuning of a robust model predictive controller for UAVs", *IFAC World Congress*, Toulouse, France, 2017.
10. Wilson, S., Glotfelter, P., Wang, L., Mayya, S., Notomista, G., Mote, M., & Egerstedt, M. The Robotarium: Globally Impactful Opportunities, Challenges, and Lessons Learned in Remote-Access, Distributed Control of Multirobot Systems. IEEE Control Systems Magazine, 40(1), 26-44, 2020.
11. C. Stoica Maniu, C. Vlad, T. Chevet, S. Bertrand, A. Venturino, G. Rousseau, S. Olaru, "Control systems engineering made easy: motivating students through experimentation on UAVs", 21th IFAC World Congress, Demonstrator Late Breaking Results, Berlin, Germany, 12-17 July, 2020.

Examples

- https://www.youtube.com/watch?v=hyGJBV1xnJI

- https://www.youtube.com/watch?v=YQIMGV5vtd4
- https://www.youtube.com/watch?v=fdrmahUPwaI
- http://www.asctec.de/en/uav-uas-drones-rpas-roav/asctec-hummingbird/

Resources

Pedagogical team: Cristina Stoica, Cristina Vlad, Sorin Olaru

Teaching staff (to be confirmed): Sylvain Bertrand (ONERA), Pedro Castillo (UTC Heudiasyc), Cristina Stoica, Cristina Vlad, Sorin Olaru.

Funding via the project MEECOD – *Moderniser l'Enseignement par l'Expérimentation sur la Coordination de Drones*, *with the support of UPSaclay on « Initiatives Pédagogiques – Oser ! » 2018, N°FOR-2018-070*, was obtained for the purchase of the necessary equipment (flight arena equipement, numerous Crazyflie UAVs and TurtleBot GAVs, etc.) for this course and the construction of an indoor space at CentraleSupélec dedicated to UAVs flight tests (room VI.003, Eiffel building).

Funding via the project DAReTeach – Drone Arenas-based Remote International Teaching with the support of *FACE Fondation – French-American Cultural Exchange in Education and the Arts* allowed to complete the fleet of Crazyflies UAVs.

Funding via the project (Re)CreativeRobot – *(Re)Creative Mobile Robotics for Kids* with the support of *the International Federation of Automatic Control Fondation* allowed to complete the fleet of DJI UAVs and ground robots.

Learning outcomes covered on the course

After completion of this course, students will be able to:

- Describe and recognize the behavior of a multi-agent system (state-of-the-art on the subject);
- Model a multi-agent system via a state-space representation;
- Analyze time-domain or frequency specifications and propose a control law for a multi-agent system in order to fulfill the considered specifications;
- Design a control law for the multi-agent system and validate it in simulation;
- Validate the proposed control law on an available experimental testbed (a UAVs/GAVs formation).

Description of the skills acquired at the end of the course

C1.2 – Modeling: using and developing the appropriate models, choosing the right modeling scale and the relevant simplifying assumptions
C1.4 – Design: specify, implement and validate all or part of a complex system
C2.3 – Identify and independently acquire new knowledge and skills
C5.3 – Analyze global and / or local issues internationally and adapt projects or solutions to them
C7.1 – Know how to convince basically: Structure your ideas and arguments, be synthetic (assumptions, objectives, expected results, approach and value created)
C7.3 – Know how to convince about yourself: Being comfortable and being convinced, showing empathy and managing your emotions
C8.1 – Build the collective to work as a team
C8.2 – Mobilize and train a collective by showing leadership

2EL1210 – Exposure of people to electromagnetism and electromagnetic compatibility

Instructors : **Dominique Lecointe**
Department : **DÉPARTEMENT ÉLECTRONIQUE ET ÉLECTROMAGNÉTISME**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

Maxwell's theory has been a source of innovation and technological progress for more than a century and it is remarkable to note the extent of the industrial sectors impacted by the applications of this theory:
- the telecommunications sector at the heart of the information society,
- the aeronautics, automobile and transport sector,
- the electrical energy sector,
- the defense and security sector,
- the health and environment sector,
- the building and public works sector,
- the internet and connected objects sector.

Unfortunately, these successes and technological advances are not without compensation. The electromagnetic pollution generated by all these electrical and electronic systems has become one of the societal challenges of the 21st century. Potential victims of this pollution are electronic systems (electromagnetic compatibility) and people (exposure). Control of this pollution is the goal of electromagnetic compatibility and exposure of people to electromagnetic waves. The engineer faces a scientific but also economic challenge to meet this challenge.

Quarter number

SG6

Prerequisites (in terms of CS courses)

none

Syllabus

1. Presentation of the issues
2. EMC: sources of disturbance
3. EXPO: Field Sources
4. TD CEM: sources and order quantities
5. EMC : coupling and protection
6. EMC : means of testing, standards
7. EXPO : biological effects
8. EXPO : limits, exposure index
9. TD EXPO : fixed emitters

10. TD EMC : quantification of coupling phenomena
11. EXPO : feedback : creation of a company in the field of human exposure
12. TD EXPO: mobile telephony
13. TD EXPO: intermediate frequencies

Class components (lecture, labs, etc.)

17 courses and exercises
2 TD

Grading

1 final examination without document of 2h00.

Course support, bibliography

Compatibilité électromagnétique de P. Degauque et J. Hamelin, édition Dunod
Exposition humaine aux champs électromagnétique de P. Staebler, ISTE editions

Resources

Teaching team (names of professors): Dominique Lecointe, Dominique Picard, stephane Pannetrat
Size of TD: 2 groups of 20 students (maximum)

Learning outcomes covered on the course

At the end of this lesson, the student will be able to:

- pose the EMC problem when designing a complex system.
- identify, according to the frequency bands, the physical phenomena involved.
- use and implement the appropriate models (control of orders of magnitude, taking into account economic constraints).
- use rigor and critical thinking to analyze and solve people's exposure problems.
- argue based on national and international regulations.

These different learning outcomes validate milestones 1 and 2 in skill C1, milestones 1 and 2 in skill C2.

Description of the skills acquired at the end of the course

These different learning outcomes enable the validation of milestones 1 and 2 of competency C1: Analyzing, designing and building complex systems with scientific, technological, human and economic components.
These different learning outcomes make it possible to validate milestones 1 and 2 of competence C2: Develop in-depth competence in an engineering field and in a family of professions.

2EL1230 – Embedded space systems

Instructors : **Laurent Bourgois**
Department : **DÉPARTEMENT ÉLECTRONIQUE ET ÉLECTROMAGNÉTISME**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

To have a global vision of today's space world and its strategic stakes, and to discover in detail the principles and technologies implemented in the design of embedded space systems, a field where the challenges are played out at the nanometer scale as well as at the light-year scale.

- Attitude and orbit control **S**ystem.
- Fault **P**ropagation & reliability.
- **A**vionics & on-board software.
- Image **C**ompression & signal processing.
- Digital **E**lectronics & corrective codes.

A visit of Airbus will conclude the module and will allow to see concretely the design and the manufacturing of space equipment at Space Electronics.
If you have found the hidden word in the five points listed above, this elective is for you. If not, this elective will give you the answer as well as many other questions.

Quarter number

SG6

Prerequisites (in terms of CS courses)

This course can be approached without any particular prerequisite for a domain. All necessary technical concepts will be explained during the module.

Syllabus

Ready for a trip to space?

Introduction to space systems
Historical context and strategic issues of access to space. Space market.
The different types of space missions and the choice of orbits.
Challenges and constraints of the space environment.

The satellite
Detailed description of the functioning and architecture of a satellite.
Sub-systems. Focus on attitude and orbit control.
Sensors, actuators, onboard computer, propulsion.

Onboard software
The different on-board processing.
Processors, memories and architectures used.

Focus on robustness, reliability, real time and validation.
Interest of hardware/software co-design.

Reliability - Validation of space systems
How to guarantee mission performance.
Types of redundancy. Fault tolerance: detection, decision, correction, reconfiguration, non propagation.
Ground test and validation of space systems.

Electronic equipment & signal processing
Signal processing techniques used.
Focus on image compression algorithms.
Specificities of space electronic systems compared to " terrestrial " equipment.
Digital electronics. Trends in new components (ASIC/FPGA).
Focus on radiation hardening. Error correcting codes.

Visit of an industrial site
Airbus Defence and Space (Elancourt): design office, engineering and manufacturing (clean rooms).

Class components (lecture, labs, etc.)

Lectures given by speakers from the industry, experts in their field and different for each module.
Visit of the Airbus Defence and Space site (Elancourt) on a full day.

Grading

Assessment in the form of an oral presentation on a space-related subject.
The weighting of the oral presentation and MCQs will be as follows: 24% for the MCQs and 76% for the oral presentation.
- A final test (CF) in the form of an oral presentation on a subject related to space: alpha_f = 0.76.

- 8 quizzes at the beginning of the session for continuous assessment (CC1, CC2, ... , CC8): alpha_1 = alpha_2 = ... = alpha_8 = 0.03.

Resources

Teaching team composed of a CentraleSupélec referent (Laurent Bourgois) and several speakers from industry, experts in their field at Airbus Defence and Space.

Learning outcomes covered on the course

Upon completion of this module, students will have a comprehensive knowledge of space systems and will be able to intervene in the design of embedded systems operating in hostile environments. They will understand why and how to deal with mechanical, thermal, radiative and electromagnetic stresses.
Emphasis will also be placed on the variety of activities related to embedded systems and the interfaces with related professions: from silicon to the complete system, from hardware to software, from design to validation.

Description of the skills acquired at the end of the course

C1: Analyze, design and build complex systems.
C2: Develop skills in an engineering field and in a profession.

Competencies C1 and C2 are validated if the overall score of the elective is greater than or equal to 10/20.

2EL1240 – Navigation and optronics systems for autonomous vehicles and satellites - Real-time technologies

Instructors : **Dominique Lecointe**
Department : **DÉPARTEMENT ÉLECTRONIQUE ET ÉLECTROMAGNÉTISME**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

This course is delivered by a team of engineers from the company SAFRAN. It is aimed at students who are interested in inertial and optronic navigation for autonomous vehicles, whether they are terrestrial, maritime, aerial, or space-based. Inertial navigation is a navigation method that uses measurements of a vehicle's acceleration and rotation to determine its position and orientation in space. Optronics, on the other hand, concerns the use of optical systems for the detection and measurement of light, which can be used for object recognition, motion detection, and surveillance.

The course will cover the fundamental principles of inertial and optronic navigation, as well as associated technologies. Students will learn how these techniques are used in autonomous vehicles such as self-driving cars, drones, unmanned aircraft, autonomous submarines, etc., to enable autonomous navigation and surveillance. The course will also cover the challenges associated with the use of inertial and optronic navigation, such as atmospheric disturbances, energy management, electromagnetic interference, etc.

Finally, students will have the opportunity to discover the latest advances in this field in terms of research and practical applications. By taking this course, students will be able to gain a solid understanding of the principles of inertial and optronic navigation for autonomous vehicles, whether they are terrestrial, aeronautical, or space-based, and be ready to meet the technical challenges associated with the autonomy of these vehicles.

Quarter number

SG6

Prerequisites (in terms of CS courses)

none

Syllabus

1. Inertial navigation: sensors, equipment, and navigation systems
2. Optronics: observation and identification, cameras, and sights
3. Space: satellites, communications, and observations
4. Autonomous vehicles: sensor fusion and autonomy

Class components (lecture, labs, etc.)

Presentation in the form of conferences

Grading

The students work in groups and prepare a presentation on a topic complementary to the concepts presented during the course. The topic will be specified at the beginning of the course. All students attend the presentations.

Course support, bibliography

Slides presented during the conferences

Resources

This course is conducted by a team of engineers from the SAFRAN company. A visit to certain sites of the SAFRAN company illustrates the problems presented during the course.

Learning outcomes covered on the course

At the end of this course, here are some learning outcomes obtained by the students:

- A deep understanding of the fundamental principles of inertial and optronic navigation.
- Knowledge of the different sensor technologies used in navigation systems for autonomous vehicles.
- The ability to understand the limitations and challenges associated with the use of these sensor technologies, such as atmospheric disturbances, electromagnetic interference, measurement errors, and drift.
- Mastery of sensor data fusion techniques to improve navigation accuracy.

- Knowledge of the latest advances in research and practical applications in the field of navigation for autonomous vehicles.

These different learning outcomes allow the validation of milestones 1 and 2 of competency C1, milestones 1 and 2 of competency C2, and milestones 1 and 2 of competency C2.

Description of the skills acquired at the end of the course

These different learning outcomes allow the validation of milestones 1 and 2 of competency C1: Analyze, design and implement complex systems with scientific, technological, human and economic components. These different learning outcomes allow the validation of milestones 1 and 2 of competency C2: Develop an in-depth competence in an engineering domain and in a family of professions.

2EL1310 – Renewable energies

Instructors : **Simon Meunier**
Department : **DÉPARTEMENT SYSTÈMES D'ÉNERGIE ÉLECTRIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

This elective includes courses, tutorials and a project.
The objective of this course is to present the potentials of systems using renewable energy sources.
The first part is devoted to the main components for producing energy from renewable sources.
A second part concerns the integration of renewable energy sources and the energy management in the electrical grid. Conversion and storage components used in this framework are also presented

Project:
The title of the project: Sizing of the renewable energy system to supply an agricultural farm.
The students are divided into several groups. Slots are planned to answer to the questions of the students.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Elective 1A "Electric energy" or equivalent

Syllabus

- Main sources of energy production from renewable sources : wind, solar photovoltaic, solar thermal, organic Rankine cycle
- Integration and energy management : wind and solar energy into electricity networks
- Hydrogen sector : production, storage, use
- Case of autonomous isolated networks: modeling and sizing of elements, management of power flows

Class components (lecture, labs, etc.)

Courses, tutorials, project.

Grading

The course evaluation method: The evaluation will be done by a 2h written exam and the project will be graded.
The evaluation score: 75% for the written exam and 25% for the project.

Resources

Teaching staff (names of lecturers): lecturers from CentraleSupélec and from the industry
Size of tutorial class (default 35 students): 18 (for a cohort of 72 students)

Learning outcomes covered on the course

1. Master the characteristics of the various components involved in the generation, conversion and management of energy from renewable sources
2. Understand the difficulties related to the integration of these means of production in the electrical networks
3. Solve simple sizing problems of energy supply systems based on renewable sources.
4. Evaluate the economic aspects

Description of the skills acquired at the end of the course

C1.3 Apply problem-solving through approximation, simulation and experimentation.
C1.4 Design, detail and corroborate a whole or part of a complex system. Milestone (*jalon)* 1: Specify and design a system or part of a system
C3.7 Make pragmatic and informed choices with the aim of producing tangible results. Milestone (*jalon*) 1: Choose the most promising solution for a given problem

2EL1315 – Electrical Energy Conversion for renewable energy sources and electromobility

Instructors : **Marc Petit**
Department : **DÉPARTEMENT SYSTÈMES D'ÉNERGIE ÉLECTRIQUE**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

Considering the decarbonation objectives at worldwide level, the European Commission has planned an ambitious program to reach a net zero emission in 2050. In that way, several scenarios have been built, among them a larger electrification of the energy sector, a better energy efficiency, and development of hydrogen. These scenarios have been also organized in seven strategic priorities. Two of them are the development of renewable energy (with a target of 80% of electricity generated from renewable sources in 2050) and a more electrified mobility. Thus electrical (or electromechanical) converters will be at the heart of this evolution, with the following applications: windmills, PV generation, battery storage, electric powertrain for electric vehicles (EV), more electric aircrafts, all electric ships, new DC lines for electrical grids, power converters for electrolysers and for fuel-cells, energy harvesting for autonomous systems, …

Whatever the application, an important step will be the design of the optimal solution and its operation in a complex and fully interconnected environment. Thus a deep understanding of the devices and sub-systems is a key point. It means: what is the structure? how does it work? how can the devices be connected together? how to design a more complex system with several devices? How to model them for the optimization and the sizing?

Quarter number

SG8

Prerequisites (in terms of CS courses)

basics about electrical circuits, 3-phase systems, and electrical powers

Syllabus

- Basics about electromechanical converters (AC machines) for generation (wind turbine and hydro power plants) and motor applications (pumping, electric propulsion). Modelling for the sizing, and for simulations

- Basics about power electronic converters for EV (battery BEV and plug-in hybrid PHEV) charging, and electric propulsion (EV, ships, trains). Modelling for the sizing, and for simulations.

- Applications:
a) Connection of an AC generator to an AC power network. Operating point setting in the P,Q diagram.
b) Electronic power converters design for charging an EV battery

Class components (lecture, labs, etc.)

slides of the lecture (with their detailed and written comments)

Grading

75% of the mark is from a 2h individual examination (knowledge questions + exercice)

25% of the mark is based on the lab session reports. If you are absent from a practical session, you will receive a mark of '0' for that session.

Resources

lectures (13h30) + lab sessions (6h) + exercices (9h)

Learning outcomes covered on the course

Based on selected applications (such as charging system for EV battery, variable speed drive for industrial application or electric propulsion, electrical generator for hydro power plant), we aim at presenting the basics about electromechanical converters and power electronic converters.

Description of the skills acquired at the end of the course

The students will know the basic components to build some widely used electric energy converters. They will be able to make a first sizing of such system, and they will be able to analyze the integration of such system in a wider environment
skills: C1.1 ; C1.2 ; C1.4

2EL1320 – Energy conversion

Instructors : **Bruno Lorcet**
Department : **DÉPARTEMENT SYSTÈMES D'ÉNERGIE ÉLECTRIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The design of systems for the production and use of energy must now be done with respect for the environment and with strict criteria for sustainable development. In addition, the availability of energy in a suitable form is the key to developing new applications in all areas, from transportation to mobile device design. Thus, all sectors of activity must today be given the means to master electrical energy, the only vector capable of meeting these needs.The energy conversion course introduces the main objects, motors and generators, allowing transformations between electrical energy and mechanical energy. It also deals with principles and electronic devices to optimize the transfer of energy between source and electric load. The converters concerned are ubiquitous in the transport of energy and renewable energies, but also in most modern objects consuming electricity.

The course begins with the positioning of the principles and systems that will be studied in relation to the basics already acquired by students in the field of electrical energy. The focus is on the industrial and economic stakes of energy management.The first part of the course is devoted to the study of AC rotating electrical machines, which are today major players in the production and consumption of electrical energy. Based on the basics of low-frequency electromagnetism and mechanics, the principles of synchronous and asynchronous machine operation are introduced in order to obtain a circuit model that can be used in a steady state. It then becomes possible to draw up an energetic balance of the conversion and to present some modes of piloting.In a second part, we discuss the components and electronic power converters. The importance of electronic switching operation and its connection with the topological and thermal aspects of the design is emphasized. The various structures are then presented using a methodology that allows classification of the converters according to the sources and electrical loads concerned and the possible reversibility of the energy transfer.

Quarter number

SG6

Prerequisites (in terms of CS courses)

SPI course 1A "Electric energy" or equivalent

Syllabus

Introduction
Energy conversion and electrical engineering
General Concepts on AC Machines
Sinusoidal field distribution - Rotating field creation - Practical realization
Synchronous machine in steady state
Principle and practical realization - Fundamental equations - Equivalent diagram - Alternator operation - Motor use

Asynchronous motor in steady state
Principle and practical realization - Fundamental equations - Equivalent scheme - Implementation on a fixed frequency network - Variable frequency power supply
Basics of power electronics
Principles of static converters: realized functions, classical structures - Ideal switch, real switches: switching regime, losses - Main components: fundamental properties, control principles, areas of use, limits
DC-DC converters
Objectives - Chopper: fundamental structures - Different operating regimes - Reversibility - Applications
DC to AC converters
Objectives - Single-phase inverters: fundamental structures - Operation modes, control laws - Three-phase inverters
AC-DC converters
Objectives - Rectifier bridges: single-phase and three-phase basic assemblies - Reversibility, line commutated inverter - Impact on the power source, power factor

Class components (lecture, labs, etc.)

L(9x1H30) // T(6x1H30) // TL(2x3H)// EE(2H)

Grading

The evaluation will be done by a written examination of 2 hours with documents. The teaching laboratory **(if it can take place in the context of Breguet building closure)** will be taken into account for 25% in the final grade of the module. Absence from a session will give the score 0 to the relevant TP.

Course support, bibliography

Théodore Wildi, « Electrical machines, drives and power systems »

Resources

Teaching staff (names of lecturers): Bruno Lorcet
Size of Tutorial (default 35 students): 18
Teaching laboratory (department and capacity): TL at the Energy Department

Learning outcomes covered on the course

At the end of this course, students will be able to:

• analyze or build an energy conversion chain
• to master all the basic components of electrical engineering
• to choose and implement an AC machine in the context of a stabilized speed application
• to make a choice of power converter and to adapt structure and control to a problem of energy conversion

Description of the skills acquired at the end of the course

C1.3 Apply problem-solving through approximation, simulation and experimentation.
C1.4 Design, detail and corroborate a whole or part of a complex system.
C2.1 Deepen a field of engineering sciences or a scientific discipline

2EL1410 – Heat Transfer

Instructors : **Gabi-Daniel Stancu**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

Heat transfer covers broad scientific and technical domains. The field of application of this discipline is characterized, among other things, by considerable spatial and temporal scales: from the nanometer (thematic of the heat transfer at nano-scale) to interstellar distances (astrophysics), from the femtosecond (thermal response of a ultra-short laser) to the characteristic time of the genesis of the universe (thermal evolution of stars). Heat transfer concerns also society subjects and major challenges such as energy (energy optimization of industrial processes, thermal insulation of buildings, ...), environment (global warming, atmospheric greenhouse effect, etc.) or transport (optimization of thermal engines, fuel cells and hydrogen sector, ...). It is inherently a discipline in which the physical phenomena are of very different natures, coexist and are coupled.

This course develops and extends the concepts of heat transfer introduced in the courses "Transport phenomena" and "Modeling and simulation of unsteady heat transfer". Furthermore, the emphasis here is on the achievement of basic notions (via simple exercises - EAI) and on the techniques of physical modeling of the heat transfer (via synthesis problems- PbS).

Domain interests:
Design, master and control any system or process in any field where heat transfers appear such as residential and tertiary housing, transport, industry, energy production, etc.. Some universe sciences (meteorology, geophysics, ...) as well as the environmental sciences also rely partly on the control of heat transfers.

Teaching objective:
Address the main heat transfer modes in simple cases. This scientific training is intended for future generalist engineers, a priori not specialists in the discipline.
This is a basic teaching of: steady and unsteady conduction; radiation between opaque bodies in a transparent environment; forced, natural, laminar and turbulent convection (phenomenological approach).The treatment of exercises and problems during tutorials is an opportunity to apply the knowledge introduced during lectures and to develop simple energy balance models. It involves solving concrete industrial, environmental or metrological problems (using an inductive approach). Using simple examples, some exercises of a didactic character introduce fundamental notions in heat transfer. Synthesis problems are proposed at the end of the course. In these, the main difficulty is to build the thread of the solution (confrontation with unclear and uncertain).
In addition, many exercises are treated in the course book. They are an excellent training.

Quarter number

SG6 and SG8

Prerequisites (in terms of CS courses)

Ideally, the students have taken the courses "Transport Phenomena" (elective course 1A, SG1or SG3) and "Modeling and simulation of unsteady heat transfer" (specific course in energy 1A, ST2). However, students who have not taken the two courses will be able to follow this elective but they will have, before the sessions, to work the courses that are available on the E-learning platform "E-SELF-LEARNING".

Syllabus

• Lecture BASICS OF HEAT TRANSFER: Conduction, convection, radiation. Introduction to conducto-convective transfer.Steady state energy balance of a fixed system at rest. Electrical analogy.
o Tutorial (EAI) Wall between two fluids; Temperature profile in a 1D-system; (PbS) Insulation of a cryogenic container
• Lecture FIN AND FIN APPROXIMATION
o Tutorial (EAI) Heated plate; Cooling of an electronic circuit; (Pbs) Efficiency of an home radiator; Liquid temperature measurement - glove finger (home work)
• Lecture BASICS OF THERMAL RADIATION: Concept of: opaque body, transparent medium, emitted, absorbed, reflected, leaving, incident and radiative fluxes. Boundary conditions in the presence of radiative exchanges. The concept of directional spectral intensity. First expression of the radiative flux. Concept and properties of the equilibrium radiation.
o Tutorial (EAI) Calculations of solid angles and fluxes; Spectral integral calculations of Planck's law; (PbS) Principle of infrared remote sensing of a body
• Lecture RADIATIVE PROPERTIES AND RADIATIVE TRANSFER: Characterization of the surface of an opaque body: notions of emissivity, absorptivity and reflectivity.Concept of: gray body, black body and body with isotropic radiative properties. Simple models of radiative transfer: (i) isothermal convex opaque body surrounded by an isothermal black body; (ii) isothermal convex opaque body of small dimensions surrounded by an opaque isothermal enclosure.
o Tutorial (EAI) Radiation between two spheres; (PbS) Temperature of a body exposed to solar radiation
• Lecture GENERAL METHOD OF RADIATIVE TRANSFER BETWEEN OPAQUE BODIES IN TRANSPARENT ENVIRONMENT: Basic assumptions of the method. Expression of the leaving and incident fluxes. Expression of the leaving energy rate. Concept of view factor - properties. Equations for a closed enclosure made up of gray surfaces. Generalization to non-gray surfaces.
o Tutorial (EAI) Radiation « face to face »; (PbS) Radiative screen - temperature measurement by a thermocouple
• Lecture UNSTEADY DIFFUSION: HEAT CONDUCTION (1/2): Energy balance equation and boundary conditions. Notion of thermal diffusivity. General theorems: superposition and Π theorems. Application to a semi-infinite geometry (response to short times): problems of imposed temperature, imposed flux and forced periodic excitation
o Tutorial (EAI) Modeling of a 2D unsteady conduction problem; 1D unsteady conduction - analytical solution in case of imposed flux; (PbS) Thermal inertia of a building (1/2)
• Lecture UNSTEADY DIFFUSION: HEAT CONDUCTION (2/2): Application to a semi-infinite geometry (response to short times - continued): problem of the thermal contact of two bodies. Case of finite media. Conductive and conducto-convective characteristic times, Biot number – recall the fin approximation
o Tutorial (EAI) Cooling of a transparent ball (PbS) Thermal inertia of a building (2/2); Laser treatment of steel
• Lecture PHENOMENOLOGICAL APPROACH OF EXTERNAL FORCED CONVECTION: Diffusion (at wall) and convection (far from wall) fluxes. Concept of fluid viscosity. Problem of the plate at imposed temperature. Dimensional analysis. Correlation general form for external forced convection. Introduction and physical meanings of characteristic dimensionless numbers. Similarity notions in forced convection. Criteria of transition between laminar and turbulent regimes in standard configurations. Evolution of the local transfer coefficient along a plate; leading edge effect.
o Tutorial (EAI) Bay window on forced external convection; (PbS) Conductor, prudence !
• Lecture INTERNAL FORCED CONVECTION: Basic notions on establishments of mechanical and thermal regimes and on established regimes in ducts of constant cross-section. Concept of mixing temperature. Nusselt number expression in laminar and turbulent regimes for flows in circular cross-section; physical discussion of results. Cases of ducts of non-circular cross-section; concept of hydraulic diameter.
o Tutorial (EAI) Calculation of the transfer coefficient in a semicircular channel; (PbS) Helium as a heat-exchanging fluid; Circulation of water in a tube (home work)
• Lecture DIMENSIONAL ANALYSIS OF NATURAL CONVECTION: Physical phenomenon - approximation of Boussinesq. Mechanical and thermal boundary layers. Dimensional analysis - similarity. Criterion of transition between laminar and turbulent regimes. Expressions of transfer coefficient. Specificities of internal natural convection. Iterative character of the natural convection calculation.
o Tutorial (PbS) Thermal study of double glazing
o Tutorial SYNTHESIS PROBLEMS (PbS) Energy recovery for residential tertiary; Air conditioning of a building in a hot and sunny region (home work)
• FINAL EXAM

Class components (lecture, labs, etc.)

The course is proposed in SG6 (in English) and in SG8 (in French) in the format of 19 slots of 1h30 each, 3 elements in preparation at home (3 x 1h30) and an exam session of 2h.

Grading

The first two learning outcomes constitute the minimum level of knowledge expected for any student who has taken this course. They will be evaluated during the course by short multiple-choice tests. These unrated tests will allow students to self-assess and teachers to measure the level of understanding of some fundamental notions and to detail the difficult points. Regarding the modeling activity of thermal systems, it is a complex skill to acquire. Students will learn this progressively during tutorials classes. The last session of the teaching will be an opportunity to consolidate all the modeling achievements. The learning outcomes will be assessed in the final exam (2H), which will consist of two parts. The first will focus on the assessment of the first two learning outcomes. In the second, students will be subjected to a complex modeling problem in order to evaluate the learning outcome modeling of thermal systems.

The core skill C1.2 is validated if the student accomplishes at least 50% of the part 2 of the final exam. The core skill C2.1 is validated if the student accomplishes at least 50% of the part 1 of the final exam. The final grade is the average of the grades of the two parts of the exam.

Course support, bibliography

• Book in English: « A first course in heat transfer » J. Taine, E. Iacona Editions Dunod 2011.
• Book in French: « Transferts Thermiques » Partie 1, J. Taine, F. Enguehard, E. Iacona, Dunod 2014.
• Platform « E-Self-Learning « in English : http://e-mentor-en.ecp.fr/ course presented by G.D. Stancu.
• Platform « E-Self-Learning « in French : http://e-mentor2.ecp.fr/ course presented by J. Taine.

Resources

•Teaching staff (names of instructors): Gabi Daniel Stancu, Benoit Goyeau
• Size of tutorial (TD) classes: 35
• Platforms « E-Self-Learning « in French and in English
• Software tools and number of licenses needed: non
• Experimental rooms (department and capacity): non

Learning outcomes covered on the course

At the end of this course, the students:
o Will be able to identify the different heat transfer modes present in a given configuration,
o Will be able to write and use appropriate energy balances in their local and global forms and continuity equations at the interfaces, thus, will be able to determine thermal fluxes and temperature fields in a system, and therefore will be capable to calculate local and global characteristics needed for the design of thermal systems
o Will have acquired modeling skills of thermal systems:
- List exhaustively the heat transfer phenomena present in a given system,
- Use scale analysis: (i) to make orders of magnitude estimates in order to discriminate predominant phenomena from those that can be ignored; (ii) to simplify problems a priori in three-dimensional geometries and / or unsteady towards models with analytical solutions,
- Use an inductive problem-solving approach: make appropriate and justified hypotheses which will be validated a posteriori by the resulting solutions,
- Reformulate a multi-physical and multi-scale problem with complex coupling phenomena, in a simplified version in which only the predominant phenomena have been considered,
- Model complex thermal systems and use fundamental energy balances to solve engineering problems.

Description of the skills acquired at the end of the course

• C1.2 « Choose the appropriate model (among several possible) for a given problem thanks to the right choices of modeling scale and simplifying assumptions »
• C2.1 « Deepen all knowledge in a chosen field, via the courses of the 2nd year»

2EL1420 – Fluid Mechanics

Instructors : **Ronan Vicquelin, Morgan Chabanon**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The Fluid Mechanics course extends the fundamental notions, equations, and skills previously established during the course *Sciences des Transferts* on transport phenomena to a mastery of the various complexities of fluid flows, their dynamics, and systems whose properties are governed by fluid mechanics. The course allows for reaching a confirmed level in this discipline and the corresponding applications before considering more advanced and specialized studies. The course and practice sessions take into account the recent evolutions of the field by combining experimental, numerical, and theoretical approaches to train to engineer practices and future stakes (data analysis, modeling, simulations, measurements).

The course consists of three blocks. The first one deepens the fundamental notions through theoretical tools, processing, and analysis of experimental and numerical data. A second block is dedicated to the analysis of compressible flows in different regimes (subsonic, supersonic, shock waves), thus allowing to address a vast field of applications previously out of reach when considering incompressible flows. Finally, students are invited to choose the theme of their third block in order to briefly open to a specialization among Aerodynamics, Meteorological and climatic flows, Aeronautical and space propulsion, Energy systems, Environment, Hypersonics ...

Quarter number

SG6 et SG8

Prerequisites (in terms of CS courses)

The course follows a previous one entitled *Sciences des Transferts / Transport Phenomena*. Students enrolled in this course must already be familiar with fundamental concepts and skills in fluid mechanics:

- Dimensional analysis
- Local and macroscopic balance equations for mass, species, momentum and energy
- Evolution of different fields (velocity, pressure, temperature) and their interactions
- Determination of stresses, forces, powers, efficiencies, head losses
- Boundary layer

Syllabus

Block #1: Advanced Fluid Mechanics (4 sessions)

1. Session 1: Fundamental equations and potential flows
2. Session 2: Analytical solutions et exact profile in boundary layers

3. Session 3: Macroscopic balances and jump conditions through interfaces
4. Session 4: Instabilities and Turbulence

Block #2: Compressible flows (4 sessions)

- Session 5: Gas dynamics – Isentropic flows
- Session 6: Critical conditions and isentropic efficiencies
- Session 7: Shock waves
- Session 8: Oblique shock wave and nozzle flows

Block #3: Thematic specialization (three sessions)

- Choice between different themes such as Aerodynamics, Meteorological and climatic flows, Aeronautical and space propulsion, Hypersonics, Energy systems, ...

Class components (lecture, labs, etc.)

10-course sessions: 3h00 each (1h30 of lecture followed by 1h30 of practice for sessions in blocks 1 and 2) :

- 7 lectures + 1 online lecture,
- 7 problem-solving workshop sessions + 1 online session.
- Continuous assessment with a knowledge test at the 4th and 6th session,
- 3 sessions in thematic blocks
- a final written test lasting 2 hours.
- the evaluation of the thematic blocks

Grading

3 assessments through the different blocks:
Block 1 (20%) : tests (2 x 15 min.) of knowledge
The purpose of the knowledge tests during sessions n°4 and n°6 is to verify the notions acquired during the first block of the course. The student obtains a **CA grade** out of 20. Attendance to these tests is mandatory.
Block 2 (50%): supervised written test during the last class period
The final written test lasts 2 hours. In absolute terms, all the elements of the course outside the thematic block are included in the program. In practice, the subject will be mainly related to the content of block n°2 linked to compressible flows. The test is carried out with any authorized written document. The student obtains a **CF grade** out of 20.
Block 3 (30%) : thematic block evaluation
Assessment of the thematic block is based on a specific project started during the session on a technical and scientific subject related to the theme studied. The approach and results of the project are reported in the specific format required by the block (poster, presentation or report). Students are awarded a **CB grade** out of 20, based on three global criteria for each block:

1. CB.1 (4 points): Form, clarity and structure
2. CB.2 (7 points): Personal commitment in the session, continuous work in and out of the session, special investment
3. CB.3 (9 points): Quality of study, assessment of work, results and analysis

The final score corresponds to the rounded score obtained after applying the formula

NF = 0.5 x CF + 0.3 x CB + 0.2 x CA
The final score is the rounded score obtained after applying the formula: NF = 0.5 x CF + 0.3 x CB + 0.2 x CA

Learning outcomes covered on the course

At the end of the course, the student will be able to:

- Model complex systems, a necessary step to their conception and optimization:
    - Make approximations et estimations,
    - Simplify an apparently complex system
    - Use fundamental balances to solve practical problems

- Characterize a system involving fluid flows thanks to several perspectives: simplified analytical solutions, results from numerical simulations, experimental data.
- Apply these skills to complex flow (unsteady, compressible)
- Face another disciplinary or application field related to fluid mechanics to show a rather autonomous adaptation to a new context

Description of the skills acquired at the end of the course

Core skills in CentraSupélec curriculum:

The course allows the students to validate the C1 and C2 skills in the engineering curriculum.
C1 is validated if CF >=10.
C2 is validated if NF>=10 and CB >= 12.

2EL1430 – Nuclear engineering

Instructors : **Pascal Yvon**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

This course will present the operating principles of nuclear reactors and describe in details all the stages of the civilian nuclear fuel cycle. The students will be able to appreciate, from technical, economical and environmental perspectives, the advantages and drawbacks of this low carbon source of energy, and its role in present and future world energy landscapes.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Basic notions of physics and chemistry

Syllabus

- Principles of nuclear fission
- Operation of pressurized water reactors
- Interactions neutrons matter
- Generation IV reactor systems and Small Modular Reactors
- Natural and secondary ressources, mining methods, "yellow cake", uranium chemistry
- Uranium enrichment: isotopic separation techniques (gaseous diffusion, ultra-centrifugation, others ...)
- Fuel fabrication and in pile behavior
- Circular economy, reprocessing and waste management: spent fuel recycling
- Transport of nuclear materials
- Futures trends and R&D: a young proven energy with even more promises

Class components (lecture, labs, etc.)

28,5 h of lectures
4,5 of personal work ahead of the lectures

Grading

Written exam of 2 hours (without class notes) - Oral repeats

Course support, bibliography

Documnts and videos available on edunao

Learning outcomes covered on the course

- Operating principles of pressurized water reactors
- Abundance of resources of uranium, the only natural fissile material
- Introduction to mining, enrichment and reprocessing technologies for the nuclear "fuel"
- Impact of neutron irradiation on microstructure and behavior of materials
- Fabrication and behavior of nuclear fuel
- Radioactif waste management: issues and solutions
- Future developments and prospective for nuclear processes and technologies (Generation IV, SMR)

Description of the skills acquired at the end of the course

Good understanding of the operation of pressurized water reactors and of the nuclear fuel cycle. Understanding of the stakes of electricity production and of the position of nuclear energy in a low carbon mix.

2EL1440 – Modeling and numerical simulation of reactive media

Instructors : **Benoît Fiorina**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

Reactive media cover a vast field of studies that fit perfectly into the current energy and environmental context. From a scientific point of view, reactive media include combustion and plasmas. From one side, combustion accounts for 80% of primary energy conversion, and is present in the energy, transport and process sectors. On the other side, plasmas represent more than 99% of the visible matter in the universe. Plasma are used in a wide range of industrial applications: energy, semiconductor manufacturing, transformation and treatment processes, and health.

The aim of this course is to introduce fundamentals of combustion and plasmas. It focuses on the importance of numerical modelling, which is a key element of research and development strategies in reactive systems engineering. To illustrate the field of application of reactive media in the field of energy, students will build a multi-physics numerical tool to simulate an emerging and promising technology based on plasma-assisted combustion of a hydrogen turbine.

Quarter number

SG6

Prerequisites (in terms of CS courses)

none

Syllabus

1. General introduction. Industrial applications and scientific challenges
a. Combustion - (1h30)
b. Plasmas – (1h30)

2. Description of a reactive system
a. Lecture (1h30)
i. Chemical thermodynamics
ii. Mixture equivalence ratio
iii. Computation of burnt gases temperature
b. Class Work (1h30) “Decreasing CO2 emissions by addition of di-hydrogen”

3. Numerical tools
a. Matlab initiation (1h30)
i. Using Matlab basic functions

ii. Using the chemical package
b. Class Work (1h30) “Computation of adiabatic combustion temperature of H2-O2 and H2-air reactive systems under global-step reaction assumption ”

4. Thermodynamical equilibrium
a. Lecture (1h30)
i. Second law of thermodynamic
ii. Methods for computing chemical equilibrium state
b. Class Work (1h30) “Computation of equilibrium composition in H2-O2 and H2-air reactive systems ”

5. Combustion chemical kinetics
a. Lecture (1h30)
b. Class Work (1h30) “Computation of auto-ignition in a constant pressure reactor”

6. Plasma production from electric discharges
a. Lecture (1h30)
b. Class Work and experimental demonstration (1h30)

7. Two temperature chemical kinetics in plasma
a. Lecture (1h30)
b. Class Work (1h30)

8. Optimization of energy in plasma discharges
a. Lecture (1h30)
b. Class Work (1h30)

9. Plasma assisted combustion
a. Experiments and models (0h45)
b. Simulations (0h45)
c. EM2C visit and mini-project presentation (1h30)

10. Mini-project : numerical simulation of plasma-assisted combustion
(3h00)

11. Mini-project : numerical simulation of plasma-assisted combustion
(3h00)

Class components (lecture, labs, etc.)

Lecture, tutorial and computer work

Grading

Restitution of the work carried out in TD and during the mini-project in the form of an oral presentation

Course support, bibliography

Nasser Darabiha, Emile Esposito, François Lacas et Denis Veynante, Poly de combustion de CentraleSupélec.
- Kenneth Kuo, Principle of Combustion, published by John Wiley & Son, 2005
- Principles of Plasma Discharges and Materials Processing, Michael A. Lieberman and Allan J. Lichtenberg, John Wiley and Sons, New York, 2nd edition, 2005
- Partially Ionized Gases, M. Mitchner and C.H. Kruger, John Wiley & Sons, New York, 1973.
- Gas Discharge Physics, Yu. P. Raizer, Springer Verlag, Berlin, 1997

Resources

Teaching team: Pr. Benoît Fiorina and Pr. Christophe Laux.

Learning outcomes covered on the course

To dimension reactive systems, an engineer has to make approximations and calculate orders of magnitude. He has to calculate mass, chemical species and energy balances. He must determine the thermochemical equilibrium of a reactive system and know how to exploit thermochemical imbalances. In particular, this course provides the following skills:

- Understand the industrial, energy and environmental stakes of combustion and plasmas.

- Be able to establish the fundamental equations for dimensioning combustion and plasma systems

- Characterize the thermodynamic and chemical transient and equilibrium states of a reactive system

-Be able to program (under Matlab environment) a numerical simulation tool for chemical reactors with detailed kinetics. The code developed by the student will be based on a MATLAB library of pre-existing thermochemical functions.

Description of the skills acquired at the end of the course

To design reactive systems, engineers must make approximations and calculate orders of magnitude. They must carry out mass, chemical and energy balances. They must determine the thermo-chemical equilibrium of a reactive system and know how to exploit thermo-chemical imbalances. This course provides for that purpose the following skills:
- Understand the industrial, energy and environmental challenges of combustion and plasmas
- Establish the fundamental equations for designing combustion and plasma systems
- Characterize the thermochemical transient and equilibrium states of a reactive system
- Program (under Matlab environment) a numerical tool for chemical reactors with detailed kinetics. The code developed by the students will be based on a pre-existing MATLAB library of thermochemical functions.

2EL1450 – Structural Analysis Course

Instructors : **Karim Tarbali**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **English**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

Understanding how structures behave and whether they can withstand their own weight and protect humans against environmental factors such as earthquake, storm, landslide, etc. is crucial in designing safe and cost-efficient structures.

Methods to determine the internal forces and support reactions of classic and modern structural systems will be the focus of this course. The connection of fundamental concepts and methods with the algorithms used by structural analysis software packages in engineering practice will be attended to.

Lectures will focus on developing skill sets to identify system behaviours and analyze structures using appropriate analysis methods. Example cases will be solved as part of the teaching-learning process in the lectures and TD sessions. A project will be defined mid-way through the course and students are encouraged to work on it progressively during the remainder of the course. This project involves hand calculations and software modelling and verification of the calculated responses. The project needs to be delivered in form of a professional report (either legibly handwritten or electronic or a mixture of both) one week after the final exam. There will be two quizzes in order to reinforce the concepts learned in prior sessions.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Mechanics (for CentraleSupelec students)
Statics, Strength of Materials (or Engineering Mechanics) for international students

Syllabus

1.Overall concepts of static, dynamic, elastic, inelastic, linear, nonlinear behaviour
2.Equations of equilibrium; Supports, reactions and free-body diagrams; Stability and determinacy of reactions
3.Shear force and bending moment; Relations between load, shear force and bending moment; Principle of superposition
4.Stability and determinacy (examples with trusses and joints); Resolution at joints for trusses; Method of sections
5.Deflection by direct integration; Moment-area methods; standard cases; short note on the deflection due to shear
6.Virtual work applied to statically determinate structures; Castigliano's theorem
7.Moment distribution; slope deflection
8.Project definition; Introduction to OpenSees software
9.The stiffness approach; the flexibility approach
10.Matrix method

11.Buckling
12.Introduction to plastic and nonlinear analysis; Plastic bending of beams; plastic hinge formation

Class components (lecture, labs, etc.)

Interactive Lecture, Project-based learning

Grading

- Two quizzes (one hour long each).
- A project report (10 pages max) including hand-calculation, code snippets, software outputs, and comments on the verification and justification of results
- A 3-hour long final exam. Bringing 2 pages of support notes (on two sides of an A4 sheet without any white space) is allowed.

The final grade is calculated as follows:

Item	Share of the total grade
Quizes	30% (15% for each)
Project	35%
Final exam	35%

Course support, bibliography

1- Structural theory and analysis, Todd, J. D. (1974).
2- Structural Analysis in Theory and Practice, Williams A. (2008).

Learning outcomes covered on the course

- Demonstrate an understanding of the linear, nonlinear, determinate and indeterminate system behaviours
- Analyze truss and frame structures to determine reaction and internal forces used in design processes
- Utilize classic analysis methods, and stiffness and flexibility approaches for structural analyses
- Create conceptual connections between hand calculations and software computational workflow and conduct verification tests

Description of the skills acquired at the end of the course

- Identify determinate and indeterminate structural systems and their stability condition
- Explain material and geometric linear and nonlinear behaviours
- Calculate the reaction and internal forces of trusses and their element deformations
- Apply direct integration, moment distribution, and slope deflection methods to frame structures to determine their deformation
- Explain and apply the stiffness and flexibility methods and contrast them
- Determine the buckling force for various boundary conditions

2EL1520 – Object oriented software Engineering

Instructors : **Paolo Ballarini, Dominique Marcadet**
Department : **DÉPARTEMENT INFORMATIQUE**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Software engineering (SE) is a discipline concerned with concepts, techniques and tools aimed at the production of quality software. SE can be seen as an iterative process, that, starting from a set of requirements, yields a software product through the execution of different phases, inlcuding : design, development, documentation, maintainance, testing. The quality of the produced software is evaluated with respect to different factors, typically : the compliance with the requirements, the « openness » to modifications/extensions, the ease of maintenance/testing.
This course aims at providing engineering students with an overview to the problem of software design and development by means of the object oriented programming (OOP) paradigm. By learning the Java programming language students will acquire basic skills in the software development process using a state-of-the-art Integrated Development Environment (IDE). By focusing on object-oriented modeling, the UML language, the Javadoc-based code documentation, the Junit-based development of unit-tests, students will acquire basic skills essential to the realization of industrial software.

Quarter number

SG6 in French and SG8 in English

Prerequisites (in terms of CS courses)

- 1CC1000 : Information Systems and Programming
- 1CC2000 : Algorithmics and Complexity

Syllabus

1. Introduction to object oriented programming in Java: classes, objects, encapsulation
2. Classes composition and inheritance
3. Abstract classes, interfaces
4. Exception handling, generics, collections
5. Introduction to software engineering: UML diagrams
6. Design patterns and applications
7. Devolopment of test units with JUnit framework
8. Multi-threaded programming
9. Introduction to graphical user interface programming in Java
10. Solution of a design problem through development of a final project

Class components (lecture, labs, etc.)

- Lectures: 13h30 (SG6) - 13h30 (SG8)
- Tutorial classes: 15h00 (SG6) - 15h00 (SG8)
- Project development: 28h30
- Exam: 2h00

Grading

40% on integrated project 60% on final examination (2h00)

Course support, bibliography

- Books: "Effective Java", Joshua Bloch; "Thinking in Java", Bruce Eckel.
- Lecture notes (Paolo Ballarini)
- Lectures slides
- Tutorials with solutions

Resources

- Lecturer: Paolo BALLARINI
- 2 Tutorial classes: Paolo Ballarini, Arnault Lapitre
- Software tools: Java JDK, Eclipse/Papyrus IDE

Learning outcomes covered on the course

At the end of this course, the students will :

- be able to apply the basic elements of object oriented programming using the Java language;
- be able to solve a mildly complex programming problem using the Java language;
- be familiar with the different phases of software development cycle and choose some appropriate tools;
- be able to chose an adequate level of abstraction when working on a specific phase;
- be able to apply the principles of UML modeling in the process of software design and development;
- know how to conceive and develop simple graphical user interface programs;
- know how to apply basic design principles for development of flexible/maintainable software solutions;
- be familiar with multi-threading programming.

Description of the skills acquired at the end of the course

C2.1: Deepen a field of engineering sciences or a scientific discipline
C6.3: Specify, design, develop and test software

2EL1540 – Theoretical computing

Instructors : **Marc Aiguier, Pascale Le Gall**
Department : **DÉPARTEMENT INFORMATIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

This teaching gives a part of the fundamentals of computer science on its two paradigms of computation, which are reduction (calculation step by step) and resolution (logical inference / automatic reasoning).

Quarter number

SG8

Prerequisites (in terms of CS courses)

Algorithms and Complexity course (ST Modelling)
An interest in mathematical abstraction and reasoning

Syllabus

The course addresses the following fundamental notions:

- Induction and recurrence (well-founded sets ...).
- Computability (Gödel/Herbrand's recursive functions, Turing machines and all the associated indecidability results).
- Mathematical logic (syntax, semantics and proof systems). Propositional and first-order logics will be detailed.

The course is composed as follows:

1. Induction and recurrence.

The following notions will be presented: set theory (ordering and preordering, upper and lower bounds, well-founded sets and induction, formal systems, proofs, correctness and completeness).

- Propostional logic.

The following notions will be presented: syntax, semantics and proof systems, binary decision tree, tableaux method, DPLL algorithm, satisfiability, SAT-solvers, and proof systems (resolution, sequent calculus and natural deduction).

- Computability and complexity.

The following notions will be presented: primitive recursive and recursive functions, computable and non-computable problems, Turing machine, equivalence theorems, Church thesis, and complexity theory.

- First-order logic.

The first-order logic is an extension of propositional logic, and is the privileged logic for describing data type structures.

Class components (lecture, labs, etc.)

The course will be divided into 13,5 hours of lectures and 15 hours of tutorials.

One or more personal works (project with computer implementation or problem to be solved) will be proposed and will constitute the compulsory assessment.

Grading

The evaluation will be done by means of a project and a written exam of 2 hours.

The final grade will be divided into 50% for the compulsory assessmentt and 50% for the written exam.

For this exam, only the handout and personal notes are allowed. Electronic devices (laptops, mobile phones and tablets) are not allowed.

Course support, bibliography

Students will be provided with a handout in French, as well as TD subjects with correction elements.

Resources

- Teaching team (names of lecturers): Marc Aiguier and Pascale Le Gall
- Size of the classes: at most 35 students
- Software tools and number of licences required: the only software used (prolog, solvers, proof assistants) will be free software that students will install on their personal machines

Learning outcomes covered on the course

Understand the fundamental principles and the formal (i.e. mathematically based) tools that underlie all methods of designing, verifying and implementing computer systems.

Formalizing computing problems and mastering the fundamental theoretical tools necessary to reason about these formalizations.

These theoretical tools are based on computation models classically used for the complexity analysis of the algorithms (see the course “Algorithms and Complexity”), as well as on reasoning methods based on mathematical logic.

Description of the skills acquired at the end of the course

Formalizing computing problems and mastering the fundamental theoretical tools necessary to reason about these formalizations. These theoretical tools are based on computation models classically used for the complexity analysis of the algorithms (see the course “Algorithms and Complexity”), as well as on reasoning methods based on mathematical logic.

2EL1550 – High Performance Computing

Instructors : **Stephane Vialle**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Students will acquire:

- Some understanding of stakes and locks of intensive numerical simulation applied to any research and development issues.
- Some understanding of parallel algorithmic and experience of each step of a computing code parallelization.
- Some knowledge and experience about parallel computing environments.

Quarter number

SG6

Prerequisites (in terms of CS courses)

SG1 common course « *Systèmes d'Information et Programmation* » (1CC1000)

1. ST2 common course « *Algorithmique et complexité* » (1CC2000)
2. *Basic knowledge in linear algebra*

Syllabus

- **Parallel and distributed architectures:** components of a supercomputer; memory hierarchy; energy aspects; need for fault tolerance.
- **Optimization and parallelization of loops in shared memory:** optimization and vectorization in series, algorithmic and multithreaded programming with OpenMP, analysis and rewriting of loops.
- **Distributed algorithms by sending messages:** data circulation and point-to-point communications in MPI (mpi4py): application deployment and distributed execution in MPI (OpenMPI + mpi4py); data distribution and collective communications in MPI (mpi4py); linear algebra, direct methods and iterative methods.
- **Parallel scientific computing:** strategies for solving large linear problems; iterative methods of substructuring; domain decomposition methods.
- **Performance measurement and analysis:** measurement methodology; speedup and efficiency metrics and limits; scaling metrics and limits.

Class components (lecture, labs, etc.)

Mathematic approaches and algorithms introduced during the lectures will be implemented and experimented on

computing clusters during the tutorials, and performance will be measured and analyzed. Experimentation will be an important part of the course, allowing a deep understanding of the lecture issues.

- **Composition of the face-to-face course:** lectures 18h00, tutorial 1h30, tutorials on computers 9h00 and final written exam 2h00
- **Composition of the course in autonomy:** handout reading, multithreaded programming exercises, graded practical exercises in distributed computing.

- **Possible course schedule:**
    - lectures 5 x 1h30 ;
    - *in autonomy : loop parallelisation and multithreaded programming exercises ;*
    - tutorial (on computing servers) 2 x 1h30 ;
    - lectures 3 x 1h30 + tutorial (on computing servers) 2 x 1h30 ;
    - tutorial 1x1h30 : MPI programming ;
    - *in autonomy : in-depth study of the MPI course based on a handout and a numerical analysis course based on a book chapter (distributed to students) ;*
    - tutorial (on computing servers) 2 x 1h30 ;
    - *in autonomy : ranked tutorial of distributed programming on PC clusters, with teachers available at certain times (office hours) ;*
    - lectures 4 x 1h30 ;
    - *Autonomy: exercises on solving methods ;*
    - tutorial (on computing servers) 2 x 1h30 ;
    - final written exam (2h00)
- **Tutorials (close to 36% of the course):**
    - 1 tutorial + 6 tutorial on computing servers, grouped in 2s (i.e. blocks of 3h),
    - developped codes will run on computing clusters of the *Data Center for Education* of CentraleSupélec, available from computing classrooms, or from student laptops.

Grading

Relative weights of the different examinations:

- 50% : Reports of some tutorials on computing servers
- 50% : written exam of 1h30 (at the end of the course)
- In case of a justified absence to one of the tutorials on computing servers, the grade of this latter is replaced by the grade of the final examination. In case of unjustified absence a score of 0/20 will be applied for this tutorial on machines.
- The remedial exam will consist entirely of a written exam, similar to the initial exam.

Course support, bibliography

Documents supplied to the students:

- Frédéric Magoulès, François-Xavier Roux, Guillaume Houzeaux. Parallel Scientific Computing. Wiley & Sons, Inc., 2015. Hardcover 354 pages (in English). *This course support is available in other languages: in French (Dunod, 2017), in Spanish (CIMNE, 2014), in Japanese (Morikita Publishing Co Ltd, 2015), in Hungarian (Pollack Press, 2018).*
- Numerical Methods: Slides of the lectures
- Parallel and Distributed Computing: Slides of the lectures.

Others suggested books:

- W. Gropp, E. Lusk, A. Skjellum. "Using MPI". MIT Press. 1999.
- R. Chandra, R. Menon, L. Dagum, D. Kohr, D. Maydan, J. McDonald. "Parallel Programming in OpenMP". Morgan Kaufmann Publishers. 2000.
- B. Chapman, G. Jost, R. Van Der Pas.. "Using OpenMP". MIT Press. 2007.

Resources

- **Teaching staff: Frédéric MAGOULES** and **Stéphane VIALLE**
- 64% of lectures and 36% of tutorials, with tutorial groups of 25 students working on high performance computers.
- Remote access to different computing servers and clusters (Data Center for Education of CentraleSupelec, and/or mésocentre CentraleSupelec-ENS Paris Saclay).
- Experimentation based on standard Opensource software: C/C++/Python languages, multithreading library for multicore machines (OpenMP), message passing library for computing clusters (MPI: MPICH2/OpenMPI), optimized scientific libraries (OpenBLAS).

Learning outcomes covered on the course

When finishing the course, the students will be able to:

1. **[Learning Outcomes 1* (AA1*)]** contributing to core skills **C1 C2 C6:**
    a. to tune existing numerical methods for high performance computing (HPC)
    b. to develop innovative numerical methods for high performance computing (HPC) in order to solve complex problems

- **[Learning Outcomes 2* (AA2*)]** contributing to core skills **C1 C2 C6:**
    - to design parallel algorithms for intensive simulations, according to high performance computing requirements
    - to implement parallel algorithms for intensive simulations on supercomputers or clusters of multi-core PC
    - to manage a limited set of computing resources when running an intensive simulation

    - **[Learning Outcomes 3* (AA3*)]** contributing to core skills **C1 C2 C6:**
        - to implement a complete and consistent high performance simulation:
            - to choose models under both the constraints of accuracy and scalability,
            - to choose efficient parallel implementation strategies
            - to achieve a simulation campaign with (always) limited ressources

Description of the skills acquired at the end of the course

- **C1:** Analyze, design and build complex systems with scientific, technological, human and economic components
- **C2:** Develop an in-depth skills in an engineering field and in a family of professions
- **C6:** Be operational, responsible, and innovative in the digital world

2EL1560 – Models and Systems for Big Data management

Instructors : **Nacera Seghouani**
Department : **DÉPARTEMENT INFORMATIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Existing data management technologies continue to evolve and adapt to challenges related to the heterogeneity, the volume and the velocity of data. NoSQL (Not only SQL) databases are a family of DataBase Management Systems (DBMS) which differs from the traditional relational SGBD paradigm. The purpose of such DBMSs is the simplicity of design, the horizontal scaling, the real-time access, the availability and performance in a distributed infrastructure.

The objective of *Models and Systems for Big Data Management* course is to study the theoretical foundations, the conceptual models and technologies for storing, monitoring and querying big data. From SQL to NoSQL, NoSQL the data representation models, the data querying and analytics, the performance measures in a distributed environnement are the main aspects addressed in this course.

Quarter number

SG6

Prerequisites (in terms of CS courses)

Basic knowledge of relational databases and SQL query language.
Desired basic knowledge of client/server architecture.

Syllabus

1. Conceptual models for data representation: SQL (relational) and NoSQL (document, key-value, column, graph).
2. Data querying and analytics languages.
3. Transaction concepts, ACID properties, CAP theorem.
4. Main concepts related to data distribution in a cluster.
5. Practical works on data modeling, querying real data (social network data, Wikipedia, ...).
6. Softwares: postgres, MongoDB, Neo4J, Spark-MapeReduce.

Class components (lecture, labs, etc.)

The course is organized as follows:

1. 11 slots of 1h30 of lecturer,
2. 4 slots of 3h practical/lab works.

Grading

Continuous assessment during practical/lab work classes, project, written exam (2h):

60% written exam,
20% project (last lab),
and 20% continuous assessment (quizzes related to labs, 2 best marks).

Resources

Slides, practical exercices/works and solutions, QCMs, bibliography references.
Use of different data management system softwares available on MyDocker.

Learning outcomes covered on the course

At the end of this course, students will be able to:

- choose a data management model which fits with the application and the data nature.
- define, deploy, manipulate a SQL and NoSQL database.
- acquire the fundamental concepts underlying distributed data.

Description of the skills acquired at the end of the course

C1.2 Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem
C6.4 Solve problems through mastery of computational thinking skills.
C6.5 Operate all types of data, structured or unstructured, including big data.

2EL1580 – Artificial Intelligence

Instructors : **Fabrice Popineau**
Department : **DÉPARTEMENT INFORMATIQUE**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

What do web-based information retrieval, personal assistant development, autonomous driving or automatic planning have in common?
These are all complex real-world problems that artificial intelligence (AI) aims to solve by addressing them with rigorous methods.
In this course, you will study the fundamental principles that guide these applications and implement some of these systems.
Specific topics include automatic learning, state space search, gaming, Markov decision processes, constraint satisfaction, graphic models and logic.
The main objective of the course is to provide you with a framework to address new AI problems that you may encounter in the future.
The ethical and philosophical aspects of AI will also be discussed.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Requirement: **to be fluent with Python programming**.
Information Systems and Programming Courses
Algorithmic and Complexity Course
Basics of probability: random variable, Bayes theorem

Syllabus

- Introduction - Presentation of the domain
- Agents and agent architectures
- Machine learning and reflex agents
    - Linear predictors
    - Loss function and optimization
    - Neural networks
- State representation and search
    a. Planners
    b. Adversarial search
    c. Utility functions
    d. Markov decision processes
    e. Reinforcement learning
- Variable-based representation
    - Uncertain knowledge

    - Probabilistic reasoning
    - Bayesian Networks
    - Simple and complex decision-making
- Logic-based representation
    - Propositions and predicates
    - Syntax vs. semantics
    - Inference systems
- Conclusion
    - Deeper on deep learning
    - Future of AI

Class components (lecture, labs, etc.)

After the first introduction session (1.5h), all sessions are 3h long and will consist of a mix of lectures and tutorials.
Students will be given course notes before each session. The course notes will be commented and questions answered at the beginning of the session.
Then the session will go on with exercises to apply the new notions.
At the end of each topic, time will be taken to ensure that the students can make progress on the programming assignments.

Grading

Assessment will be based entirely on coding exercises.
Students will receive task specifications for which they will have to build an "agent" program capable of handling the requested task.
Student submissions will be evaluated automatically on the basisof their performance.
Programming assignments will be published according to a schedule presented at the beginning of the module.
Each assignment will have a deadline. Penalties will be applied for late submissions.

Course support, bibliography

Artificial Intelligence : a Modern Approach, 4th ed. (English)
Auteurs : Stuart Russel, Peter Norvig
ISBN : 9780134610993
Editeur : Pearson

Resources

- Teaching team: Fabrice Popineau (in charge of the module)
- Size of the supervised work sessions (by default 25 students): 25 students, supervision capacity of 100 students with teachers (Hugo Thimonier, Arpad Rimmel, ...)
- Software tools and number of licenses required: No licenses. Free tools: Python and its libraries mostly.

Learning outcomes covered on the course

By the end of this unit, students will be able to:
- identify the problems for which artificial intelligence techniques are suitable and when it is the case to identify the appropriate techniques,
- formalize a given problem in the language/framework of different AI techniques,
- implement elementary AI algorithms (e. g. state space search algorithms),
- design and implement an evaluation of different algorithms on a formalization of a problem, and draw conclusions from this evaluation.

Description of the skills acquired at the end of the course

C1.2 Choose the right model (from among several possible) for a given problem, thanks to the right choice of modeling scale and simplifying assumptions.
C2.1 Extend knowledge in a chosen field, via 2nd year courses
C6.1 Develop heuristic methods to solve highly complex problems
C6.3 Analyze data (predictive analysis, decision-making)

2EL1590 – Cloud computing and distributed computing

Instructors : **Francesca Bugiotti, Gianluca Quercini**
Department : **DÉPARTEMENT INFORMATIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Nowadays, the marketing strategies of most companies is based on the analysis of massive and heterogeneous data that needs a considerable amount of computational power. Instead of purchasing new hardware and software infrastructures, companies often resort to the computational and storage power offered by *cloud computing* platforms over the Internet.

The objective of this course is to present the fundamental principles of *distributed systems* and *distributed computing* that are at the heart of *cloud computing*.
The course will cover the principles of virtualization and containerization and the methods and tools used for distributed processing (for instance, *MapReduce, HDFS,* and *Spark*).
The course will also introduce advanced techniques and algorithms for the analysis of massive and heterogeneous data (PageRank, supervised learning, and *clustering*) and a brief introduction to some optimized Spark-compliant data formats (i.e., Parquet).

Quarter number

SG8

Prerequisites (in terms of CS courses)

Python programming, databases, basics of networking will be appreciated.

Syllabus

Introduction

- Cloud computing: motivation and terminology.
- Introduction to the public cloud providers (Amazon AWS, Microsoft Azure).
- Setup of a virtual machine on Microsoft Azure.

Virtualisation

1. Virtualisation basics.
2. Containerisation basics.
3. Docker architecture.
4. Images, containers, volumes and networks in Docker.
5. Application deployment with Docker.

Multi-service applications and orchestration.

- Microservices architecture.
- Orchestration principles.
- Presentation of Kubernetes.
- Application deployment with Kubernetes.
- Application deployment in the cloud.

Cloud programming and software environments.

- Parallel computing, programming paradigms.
- Hadoop MapReduce.
- Apache Spark.
- Apache Parquet.

Data analysis.

- Cloud environments and data storage.
- Data distribution.
- Dataframes.

Class components (lecture, labs, etc.)

Introduction.

- Lecture : 3h

Virtualisation and containerisation.

- Lecture: 3h
- Tutorial : 3h

Multi-service applications.

- Lecture : 3h
- Tutorial : 3h
- Lab assignment (graded) : 1,5h

Cloud programming and software environments.

- Lecture : 7,5h
- Tutorial : 3h
- Lab assignment (graded) : 1,5h

- Exam: 2h

16,5h lecture, 9h tutorials, 3h lab assignments, 2h exam.

Teachers will schedule office hours and regular checkpoints to support students in completing the assignments and answer their questions.

Grading

Written examination at the end of the course (MCQ + exercises) on the Evalmee platform (paperless exam).

1. 2 lab assignments are graded.
2. Each lab counts for 30% of the final mark and the written exam for 40%.

Course support, bibliography

- Hwang, Kai, Jack Dongarra, and Geoffrey C. Fox. *Distributed and cloud computing: from parallel processing to the internet of things*. Morgan Kaufmann, 2013.
- Erl, T., Puttini, R., & Mahmood, Z. (2013). *Cloud computing: concepts, technology & architecture*. Pearson Education.
- Tel, G. (2000). *Introduction to distributed algorithms*. Cambridge university press.
- Miner, D., & Shook, A. (2012). *MapReduce Design Patterns: Building Effective Algorithms and Analytics for Hadoop and Other Systems*. O'Reilly Media, Inc.
- Karau, H., Konwinski, A., Wendell, P., & Zaharia, M. (2015). *Learning spark: lightning-fast big data analysis*. O'Reilly Media, Inc.
- Schenker, Gabriel. Learn Docker - *Fundamentals of Docker 18.x.* Packt Publishing,. Print.
- Lisdorf, Anders. *Cloud Computing Basics: A Non-technical Introduction*. Apress, 2021.
- Linthicum, David. An Insider's Guide to Cloud Computing. Addison-Wesley, 2023

Resources

Teaching staff: Francesca Bugiotti, Gianluca Quercini, Idir Ait Sadoune, Marc-Antoine Weisser, Arpad Rimmel
Maximum lab enrollment: 25 students
Software, number of licenses required: Use of free software

Learning outcomes covered on the course

At the end of this course, the students must be able to:

- Understand the fundamental concepts of cloud computing.
- Master the notion of virtualization and containerisation in the cloud.
- Be acquainted with the different cloud platforms.
- Use the distributed computing paradigms, such as MapReduce and Spark.
- Design distributed algorithms on data.

Description of the skills acquired at the end of the course

Operate all types of data, structured or unstructured, including big data
Conceive, design, implement and authenticate complex software.

2EL1710 – Advanced probabilities

Instructors : **Erick Herbin**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

This theoretical course is a follow-up to the 1st year Mathematics course, which includes the basic concepts of probability theory. It introduces the foundations of the general theory of stochastic processes, taking into account the temporal evolution of random concepts.

These probabilistic models constitute the basic mathematical objects for modelling phenomena with high variability, uncertainty or complexity that make it impossible to describe them in detail. Among them, Brownian motion is widely used to describe phenomena (natural, physical, biological or financial) based on stochastic differential equations. It is at the crossroads of important classes such as martingales, Markov processes or Gaussian processes, from which it inherits properties.

The objective of this course is the theoretical study of the first two families of stochastic processes, in the particular case where the parameters are in a discrete space, and then to introduce Gaussian processes indexed by the real ones. The course is in the classic format of a mathematics course in which the fundamental theorems are demonstrated on the board.

Quarter number

SG6

Prerequisites (in terms of CS courses)

CIP course of the CentraleSupelec curriculum or last year courses of a Mathematics Licence: Integration, Measure Theory, Probability.

Syllabus

Discrete time martingales: study of discrete time martingales; martingales and game strategy; convergence results
Markov chains: transition operators, Markov ownership and canonical Markov chain; state classification, recurrence/transience; asymptotic results
Gaussian processes and introduction to Brownian motion: law of a stochastic process; Gaussian processes, white noise and introduction to Brownian motion

Class components (lecture, labs, etc.)

Lectures entirely on the board (results, proofs and examples): 19 hrs 30
Tutorial: 9 hrs

Grading

Home Works, Personal projects, Final written exam: 2 hrs (without document, calculator or computer).

Resources

Teaching team (names of the lecturers): Erick Herbin
One TD group (full complement): Philippe Bouafia

Learning outcomes covered on the course

The objective of this course is the theoretical study of the first two families of stochastic processes, in the particular case where the parameters are in a discrete space, and then to introduce Gaussian processes indexed by the real ones.

Description of the skills acquired at the end of the course

Theoretical foundations for the study of stochastic discrete-time processes and Gaussian random processes. At the end of this course, students will be ready to take a 2nd year Stochastic Calculus course in Mathematics.
C1: Analyze, design and build complex systems with scientific, technological, human and economic components
C2.1 : Deepen a field of engineering sciences or a scientific discipline
C2.2 : Import knowledge from other fields or disciplines
C2.3 : Identify and acquire independently the new knowledge and skills required
C7 : Know how to convince
C7.1 : Structure ideas and arguments

2EL1720 – Distributions and operators

Instructors : **Pauline Lafitte**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

The goal of this theoretical course is to go back to the sources of the concepts of functional analysis that were introduced in the Analysis and Partial Differential Equations courses in first year.
Historically, the distributions and the operators were introduced to provide a formal mathematical frame for problems arising in Physics. In this way, the concepts of functions were generalized into a theory that allows to treat rigorously fundamental questions of analysis (exchanging limits, exchanging limits and integrals, Fourier transform)...
These concepts provide an answer to the main question : in which functional space do we have to search for the solution of the problem so that it is well-posed, that is, it admits one and only one solution that depends continuously on the data ? In particular, the concept of (general) topology on such spaces plays an essential role in the study of the question of continuity and, more generally, the question of convergence. Depending on the considered cases, they can be defined by a distance, a norm, a family of semi-norms...
In the general frame of the stochastic processes (or random functions), the distributions and the operators are the basic mathematical tools to study Gaussian processes or extensions of the classical Brownian motion. The concepts introduced in this course constitute the basis of the spectral or integral representation of these processes, which allow their fine study (geometric property, Markov property, definition of a stochastic integral, etc.)

Quarter number

SG6

Prerequisites (in terms of CS courses)

CIPPDE

Syllabus

This course of fundamental mathematics is organized around the theoretical study of the following notions:

- Hahn-Banach's theorems
- Unbounded operators
- Weak topologies
- Advanced concepts of distributions

For each of these subjects, the main results are rigorously proved on the blackboard.

Class components (lecture, labs, etc.)

Lectures during which the concepts and results are introduced and proved on the blackboard. These are complemented by tutorials.

Grading

Homeworks, Personal projects, Written final exam: 2 hr ; no documents allowed.

Course support, bibliography

Partial solutions of the exercises.

Resources

Lecturer: Pauline Lafitte
Labs: Alexandre Richard
One lab group

Learning outcomes covered on the course

Mastering the theoretical bases of functional analysis: the students will have all the required qualities of rigorous reasoning that are necessary for modeling and analyzing mathematically.

Description of the skills acquired at the end of the course

C1: Analyze, design and build complex systems with scientific, technological, human and economic components

C2.1: Deepen a field of engineering sciences or a scientific discipline
C2.2: Import knowledge from other fields or disciplines
C2.3: Identify and acquire independently new knowledge and skills
C7.1: Structure ideas and arguments, be synthetic (assumptions, objectives, expected results, approach, and value created)

This course gives an important basis for students who want to attend a Master 2 connected to fundamental mathematics (for instance in Analysis, Partial Differential Equations or Probability).

2EL1730 – Machine Learning

Instructors : **Nora Ouzir**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Machine learning lies at the heart of many real-world applications, including recommender systems, web search, computer vision, autonomous cars and automatic language translation. This course will provide an overview of fundamental topics and important trends in machine learning, including algorithms for supervised and unsupervised learning, dimensionality reduction methods and their applications. A substantial lab section and a data science competition will allow the students to apply machine learning theory to various real-world problems.

Quarter number

SG6

Prerequisites (in terms of CS courses)

Notions of linear algebra, probabilities/statistics, and scientific programming in Python (numpy).

Syllabus

The course will cover the following topics:

• Introduction to Machine Learning
• Model selection and evaluation
• Linear and logistic regression
• Probabilistic classifiers and linear discriminant analysis
• Non-parametric learning and nearest neighbour methods
• Tree-based methods and ensemble learning
• Support Vector Machines
• Neural networks
• Dimensionality reduction
• Unsupervised learning: clustering

Class components (lecture, labs, etc.)

Classes are split into a 1h30 lecture and a 1h30 lab. The lab sessions include theoretical exercises on the contents of the class and practical implementation in Python.

Grading

The evaluation of the course will be based on the following:

- An individual assignment including theoretical and hands-on practical questions. The aim is to solve machine learning problems from the theoretical viewpoint and familiarize the students with the exercises of the final exam.
- A group project: The students will form groups of 3 and propose a topic for their project. A final report will be submitted.
- A final exam: MCQ (multiple choice questions) exam. The first part of the exam will test different notions seen in class. The second part will contain theoretical exercises (similar to the ones seen in the lab and assignment).

The grading will be weighted as follows: individual assignment 20%, group project 20%, and final exam 60%.

Course support, bibliography

There is no single required textbook for the course. The course slides will be provided, and we will recommend specific chapters for each topic of the course based on the following books (via Edunao):

1. Shai Shalev-Shwartz and Shai Ben-David. *Understanding Machine Learning: From Theory to Algorithms*. Cambridge University Press, 2014.
2. Christopher M. Bishop. *Pattern Recognition and Machine Learning*. Springer, 2011.
3. Trevor Hastie, Robert Tibshirani, and Jerome Friedman. *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*. Second Edition, Springer, 2017.
4. Jure Leskovec, Anand Rajaraman, and Jeff Ullman. *Mining of Massive Datasets*. Cambridge University Press, 2014.

Resources

All material and supplementary resources are available on the **Edunao** page of the course. All announcements will be made through the Edunao forum. Students are kindly asked to use the forum for any questions about the course.

Learning outcomes covered on the course

By the end of the course, the students will be able to:

- Identify problems that can be solved using machine learning methodologies.
- Identify and apply the most appropriate algorithm(s) given a problem.
- Implement some of these algorithms from scratch.
- Evaluate and compare machine learning algorithms for a particular task.
- Deal with the challenges of real-world data.

2EL1740 – Algebra and cryptology

Instructors : **Remi Geraud**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **No**

Description

This lecture is an introduction to the tools and techniques of modern mathematics, with a view towards scientific and technological applications.

Exploring the crossroads where pure mathematics, computer science and information theory meet, we will address questions such as

1. How do you communicate with a deep space probe?
2. How can one assess the authenticity of a digital document?
3. How does one find very large prime numbers? How can one factor large integers into their prime divisors?
4. and many others

A leitmotiv for this course is the theory of discrete logarithms and euclidean lattices, which underpin a large portion of cryptology in the 20th and 21st centuries and intersects with many fundamental aspects of mathematics.

This lecture aims at providing students with:

- A cultural overview of the evolution of mathematics during the 20th and 21st century, along with the language that will enable them to pursue in that field
- A strong command of computational algebra, especially in finite rings and fields, and elliptic curves
- An understanding of the mathematical foundations underpinning modern cryptology

Quarter number

SG8

Prerequisites (in terms of CS courses)

This lecture does not require an dedicated mathematical background beyond that of classes préparatoires.
Some some fluency in computer programming is highly recommended.
- Warning: the course comes with **a heavy workload necessary** to develop an intuition of the discussed notions.

Syllabus

- The 2023 session discussed among others the following items:

- Applications of cyclic groups [Diffie-Hellman'76, Schnorr'89, ElGamal'85]
- Elementary constructions on finite fields [Reed-Solomon'60, Shamir'79, Toom-Cook-66]
- Elementary arithmetic algorithms [Miller-Rabin'80, Pollard'74, Dixon'81]
- Picard group of Dedekind rings and smooth projective varieties
- Lattice reduction and applications [LLL"82, Lagarias-Odlyzo'85, Wiener'02, Coppersmith'96]
- Elliptic curves over finite fields and applications [Lenstra'85, Koblitz-Miller'86, NIST'05]
- Learning with errors and applications [Regev'05, Dilithium'22]

Class components (lecture, labs, etc.)

- Blackboard lecture
- Lecture notes are handed out after each lecture
- Detailed computer algebra programs are provided
- Tutorial classes take the form of an application of each chapter's important notions

- Regular graded testing helps keeping on schedule with assimilating concepts and putting them in practice

Grading

Continuous testing

Course support, bibliography

- David Eisenbud, *Commutative Algebra (with a View Toward Algebraic Geometry)*
- Robin Hartshorne, *Algebraic Geometry*
- William Fulton, *Algebraic curves: An Introduction to Algebraic Geometry*
- Henning Stichtenoth, *Algebraic Function Fields and Codes*
- Michel Demazure, *Cours d'algèbre*
- Joseph H. Silverman, *The Arithmetic of Elliptic Curves*
- Joseph H. Silverman, *Advanced Topics in the Arithmetic of Elliptic Curves*
- Jean-Pierre Serre, *Cours d'arithmétique*
- Michael Tsfasman, Serge Vlăduţ, Dmitry Nogin, *Algebraic Geometric Codes: Basic Notions*

Resources

Lectures will mostly rely on the blackboard, with computer tools being used in later exercises. Relevant software will be provided as needed.

Teaching staff: Rémi Géraud-Stewart.

Learning outcomes covered on the course

- At the end of this course, the students will be able to

  - Recognise the presence of underlying algebraic structures in engineering problems
  - Understand the issues addressed by cryptology and code theory, know and recognise their leading industrial applications
  - Master the mathematical language in which algebraic questions are formulated and analysed

Description of the skills acquired at the end of the course

- 1. Recognise the presence of underlying algebraic structures in engineering problems
- C.1.2 : identify the structures that were discussed during lectures
- C.6.1 : invoke the relevant technological tools

2. Understand the issues addressed by cryptology and code theory, know and recognise their leading industrial applications

- C.6.7 : understand the technical aspects and difficulties related to communication and information transfer
- C.3.6 : evaluate technical solutions against specific needs and constraints
- C.6.1 and C.1.4 : introduce relevant tools and correct configurations

3. Master the mathematical language in which algebraic questions are formulated and analysed.

    - C.2.3 : practice acquiring new skills to approach a given problem

2EL1750 – Advanced statistics

Instructors : **Sarah Lemler**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

The Advanced Statistics course aims to present various statistical methods for the estimation, the prediction and for determining the properties of the proposed estimators. We will develop two themes:

- multivariate linear regression
- non-parametric statistics

The course covers both the theoretical aspects of these concepts but also proposes a practical application of the models and methods considered using TPs with R software on data sets from different domains.

To be downloaded before the first TP:

1. the R software https://www.r-project.org/
2. the RStudio interface https://www.rstudio.com/

Quarter number

SG8

Prerequisites (in terms of CS courses)

For this course the prerequisites are as follows:

You must be familiar with the concepts seen in Statistics and Learning in 1st year, in particular:

- estimators,
- confidence intervals,
- the tests,
- the first notions on the linear model

Syllabus

We will develop two themes:

- multivariate linear regression,
- non-parametric statistics.

Class components (lecture, labs, etc.)

The course will be done on the board (for the most theoretical part) or from projected slides when it will be necessary, for example, to present an application made from the R software.

There are 30,5 hours scheduled for this course, including 2 hours for the final exam.

Grading

The course consists of two evaluations: an obligatory homework assignment (DM) to be written in pairs to be returned halfway through the course (the date will be specified during the first class) and a 2-hour final exam (EX) covering the entire course. The score of this course will then be the average of the scores of the two previous evaluations ((1/3)*DM+(2/3)*EX) rounded to the nearest half point. Failing students can re-take the exam in a second session EX2 in the same way as the first session exam EX. The course's score after the second session is the one of the exam EX2 (without the DM).

Course support, bibliography

The 1st year course material of Statistics and learning written by Arthur Tenenhaus

Resources

At the end of each course, TDs or TPs exercises will be proposed to familiarize themselves with the theoretical concepts seen in class and put them into practice to answer concrete problems, possibly based on data sets.

Learning outcomes covered on the course

- Use of parametric and non-parametric statistical estimation techniques
- Validate a model and understand the limits of a statistical model
- Propose, implement and calibrate a predictive model
- Use the R software and interpret results

Description of the skills acquired at the end of the course

- Use of parametric and non-parametric statistical estimation techniques
- Validate a model and understand the limits of a statistical model
- Propose, implement and calibrate a predictive model
- Use the R software and interpret results

2EL1760 – Scientific calculation

Instructors : **Hachmi Ben Dhia**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

The course is both a rigorous and applied brick, contributing to the design of complex mechanical systems through modeling, mathematical analysis, approximation and controlled simulations of engineering problems in solids and fluid mechanics. This covers sectors such as Energy, transportation, Civil Engineering, aeronautics, aerospace, etc..

The educational goal is that students following this course gain a rigorous understanding of the chain integrating modeling, mathematical analysis and simulation for the study of such complex systems, through simplified, still relevant of solid and fluid mechanics.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Basic notions in Continuum Mechanics - Basic notions on differentiation and integration - Basic notions on Hilbert spaces (Sobolev Spaces, in particular) - notions and weak formulations of PDEs-Basic notions on stability and prime notions on appropriate space and time numerical approximations methods and schemes - Some coding notions - To sum up : a first year CS level of knowledge in Mathematics and Mechanics or a third University year in Applied Mathematics to Mechanics.

Syllabus

The course is composed of two successive parts of 5,5 x 3h, each (4.5x3h given by the teacher and 3h on free time for students, for the fluid part) and 5x3h Solids Part + 1.5h on free time for students.
1. Compressible fluid flows simulation :
- Flow models, discontinuous solutions, Entropy, Basic solvers, extensions
- Practical implementation
2. Modeling, mathematical analysis and controlled simulation in solid mechanics
-Derivation of linear elasticity equations: (recalling strong formulation) and establishing weak ones.
-Mathematical analysis of the primal weak problem. Vectoriel Finite element approximation. A priori error estimation
-Practical implementation and approximation of a singular problem (as mini-project within free time)

Class components (lecture, labs, etc.)

Classical Lectures, Tutorial (individual and collaboratif), Projects + Home Work on certain points of the CS-Course

Grading

Written exam, oral exam, ProjectEvaluation (first session) : Written exam (coef 2), Project (coef 1)Evaluation (second session) : Oral or written exam (depending of the number of students who failed the exam)

Course support, bibliography

- Handout PDEs (first CS year) and Handouts for the two parts (Fluid and Solid) of the course (and references therein)
- Matlab, Scilab, Python...

Resources

Hachmi Ben Dhia (Professeur des Universités, CentraleSupélec), LMPS et Fédération de Math CS, (Solids Part and Course manager)

Frédérique Laurent-Nègre (Chercheur CNRS), Laboratoire EM2C et Fédération de Math CS, Participant (Fluids Part of the Course)

External Assistants (PW, Projects)

Computer Rooms

Learning outcomes covered on the course

Some Basic mathematical Results, methods and tools for the analysis of continuous problems of Mechanics of solids and fluids

Some Numerical methods for approximating continuous problems (Finite Difference Schemes, Finite Volumes and Finite Elements)

Estimation of errors between continuous and approximate solution and mathematical control of convergence.

Analysis of engineering problems governed by Partial Differential Equations (PDEs)

Practice of numerical simulation, taking into account the nature mathematical properties of these PDEs
Initiation to the best fit choice of the numerical methods

Description of the skills acquired at the end of the course

Analysis of engineering problems governed by Partial Differential Equations (PDEs) - Acquire some ideas for managing complexity
Practice of numerical simulation, taking into account the mathematical properties of these PDEs
Initiation to the best fit choice of the numerical methods
Become aware of the interest of researching performance for Engineering solving engineering problems to minimize the energy impact
Integrate the interests of collaborative work

2EL1810 – Structural Dynamics & Acoustics

Instructors : **Didier Clouteau**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

Vibrations and wave propagation play an key role in many areas: geophysics, behaviour of civil engineering structure subjected to wind, earthquakes or waves, stability and comfort of aeronautical and terrestrial vehicles. Acoustics is also essential in the transportation vehicles for both internal comfort and external noise.
The aim of this course is to provide students with essential knowledge, methods and tools for the analysis and quantification of these phenomena in structural dynamics and acoustics. It will be based on a set of case-studies to illustrate the fundamental concepts of resonance and radiation.

Quarter number

SG6

Prerequisites (in terms of CS courses)

It is strongly recommended to have followed the course of mechanics of continuous media or a course on waves.

Syllabus

1. Dynamic response of an oscillator, principle of vibration reduction (Lecture)
2. Mechanical and acoustic waves and resonances (Lecture and tutorial)
3. Vibrations of beams (Lecture and tutorial)
4. Construction of reduced Multi-Degree-Of-Freedom models in dynamics (Lecture and tutorial) & reminder on continuum mechanics (self-taught)
5. Dynamic response of a complex structure (Lecture & Case-study 1.1: building under wind and earthquake loads)
6. Case-study 1.2 and 2.1 : building under wind and earthquake loads (Finite element models)
7. Introduction to advanced dynamic models (Lecture and end of Case study 2.2)
8. Acoustic radiation (Lecture and tutorial)
9. Acoustic resonance (Lecture and tutorial)
10. Case-study 3: Analysis of a scientific paper
11. Final exam

Class components (lecture, labs, etc.)

Class : 8 slots
Tutorials : 5 slots
Hands-on : 6 slots + homework

Grading

2-hr written exam (weight 0.55) + 3 continuous assessment through Case studies (weight 0.15 each)

Course support, bibliography

Lecture notes +course slides + recorded lectures in English and in French

Resources

Lectures will be given in French and recorded lectures in English will be made available to students.
Tutorial classes: 35 students with at least one in French and one in English.
Software: Comsol Multiphysics and Python notebook

Learning outcomes covered on the course

Completing this course students will be able to:

- model the dynamic behaviour of structures using a relevant model : (3D , beams,...)
-model the acoustic behaviour of an enclosure and the radiation patern of a acoustic source or an open system.
- model transient and random environmental loads (Wind , seism...)
- build a low frequency surrogate model to solve practical vibration or acoustic problems.

Description of the skills acquired at the end of the course

C1.2 Ability to model the dynamic behaviour of a structure
C1.2 Ability to model random external loads (Wind, earthquakes)
C1.2 Ability to model simple acoustic problems
C1.3 Ability to solve vibration and acoustic problems in the low frequency domain using a modal approach, either in the time or in the frequency domain

2EL1830 – Non-linear behavior of materials

Instructors : **Véronique Aubin**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The design of material structures and their optimization (in terms of service life, performance, cost) requires the ability to predict the response of the materials considered for this application under the stresses imposed during their service life (load, temperature, stress, humidity, etc.).

The objective of this course is to highlight the mechanical behaviour and durability of the main classes of materials under various loading conditions, to understand the physical basis of the micro-mechanisms involved, and to use relevant modelling for design, as part of numerical methods. The concepts are introduced as part of the mechanics of continuous media, and use concepts related to the Materials course.

Applications in transport, energy, electronic systems and civil engineering.

Quarter number

SG6

Prerequisites (in terms of CS courses)

1EL5000 Continuum mechanics
1CC3000 Model representations and analysis

Syllabus

1. Introduction, approach of modelling, recalls of continuum mechanics and thermal-elasticity
2. Anisotropic elasticity of composite materials: Introduction to composite materials (nature, interest using Ashby maps, manufacturing process). Anisotropic linear elasticity. Calculation of the properties of the equivalent homogeneous medium.
3. Polymer and elastomer viscoelasticity: Introduction to polymers (nature, behavior with respect to temperature). Viscoelasticity. Time dependent behavior.
4. Mechanisms of plasticity in metallic alloys: Structure and defects of crystalline materials. Dislocations and Schmid factor. Hardening of alloys.
5. Elastoplasticity: Description of elastic domain changes. Strain decomposition. Incremental 3D elastoplasticity.
6. Safety of structures - damage and fracture: introduction to concrete (nature and specificities in behavior and damage). Volume damage. Crack sustainability.
7. Choice of a model - case study. (On 2 given cases, analyze the problem, propose/create a model able to account for the physical mechanisms observed.)
8. Coupled models.
9. Conference and Case study (use of the various concepts of the course on a given application)
10. Case study(use of the various concepts of the course on a given application) - revisions before examination
11. Final examination

Class components (lecture, labs, etc.)

- Sessions 1 to 6: lecture + directed study session
- Session 7: working session
- Sessions 8: lecture + directed study session
- Sessions 9 and 10: working session
- Session 11: final exam 2H

Grading

The final examination consists in one exam (70% of the grade) and a report on a case study (30% of the grade). As examination and case study report assess different skills, both will be required for remedial where applicable.

Course support, bibliography

No handout, but a list of books.
Chaboche and Lemaître, Mechanics of Materials, Dunod
Roesler, Harders, Baeker, Mechanical Behaviour of Engineering Materials, Springer, 2007
Besson, Cailletaud, Chaboche, Forest, Non linear Mechanics of Materials, Hermès, 2001

Resources

• Teaching staff (instructor(s) names): Véronique Aubin, Camille Gandiolle, Jan Neggers
• Maximum enrollment (default 35 students): 70

Learning outcomes covered on the course

At the end of this course, students will be able to:

- analyse a material structure, list the loadings applied to it, explain the criteria to which it must respond (performance, economic, etc.).
- interpret the experimental mechanical behaviour of a given material from the physical mechanisms involved, discriminate between several possible interpretations.
- select, use and enrich a constitutive law suitable for the observed experimental behavior
- Persuade at the level of core values; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. To make the added value known.

Description of the skills acquired at the end of the course

The course allows for progress in the C1 and C2 skills

2EL1840 – Building Tomorrow - Mechanics Applied to Civil Engineering

Instructors : **Brice Bossan**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The aim is to materialize a project for a construction in the future, and therefore to simultaneously exercise innovation and scientific skills, and also to work in project mode ...
Through this problematic posed by a constrained and different environment from that of the Earth today, students develop their innovation capacities and acquire skills in Civil Engineering, Materials, Thermal, Construction & Logistics, and also Environmental...
As the tutorials are done in sub-groups, students acquire skills in teamwork, transdisciplinary project management, reporting and scientific communication during project reviews and the final defense.

Quarter number

SG6

Prerequisites (in terms of CS courses)

1EL3000 - Industrial Engineering or 1EL4000 - Materials or 1EL5000 - Continuum Mechanics or 1EL7000 - Transfer Sciences

Syllabus

Session 1 (1h30): launching lecture, constitution of the 4 project groups, commented bibliography in 4 groups of 25 students.
Sessions 2, 4, 6, 8 (4 times 3 hours): tutorials in 4 groups of 25 students (working in parallel) with a science facilitator present for each group. The scientist then gives the theoretical (1h30) and applied (1h30) lessons that the students need to progress in their work.
Sessions 3, 5, 7, 9 (4 times 3 hours): alternating with sessions 2, 4, 6, 8 the project review (carried for each group) allows the students to measure the progress of the work on all the themes, to make coherent choices and to record what they have learned, then to identify the locks to be lifted for the good continuation of the work they will do in TD, and in personal work.
Session 10 (3 hours) : restitution of the work via a presentation in the lecture hall of the 4 groups of 25 as well as a synthesis of the solution by the 4 rapporteurs of the 4 groups. The evaluation of the students is done by the course leaders + the scientific and innovation facilitators.

Grading

The individual evaluation of the students is done "continuously" by the Scientist during the TD/TP, that of the group is done during sessions 3-5-7-9 and 10.

Resources

Teaching staff: B.Bossan is responsible for the organization of the elective. Each theme is piloted by a scientist.
Size of the TDs: 4 groups of 25 students

Description of the skills acquired at the end of the course

C2 Develop in-depth skills in an engineering field and a family of process. C7 Know how to covince. C8 Lead a project, a team.

2EL1850 – Simulation of multiphysic couplings with FEM

Instructors : **Guillaume Puel**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The aim of this class is to give theoretical and applied insights on multiphysic couplings simulations such as: thermomechanical, piezoelectric, vibroacoustic, magnetomechanic.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Partial Differential Equations
1EL1010 - Radiation and propagation or 1EL1500 - Physics of waves or 1EL4000 - Materials or 1EL5000 - Continuum mechanics or 1EL7000 - Transport phenomena

Syllabus

- S1(1h30)-S2-S3 Variational formulation and 1D FEM / Application: thermoelastic beam (weak thermo-mechanical coupling)
- S4-S5 2D FEM / Application: heated room with an open window (weak coupling: heat transfer and fluid mechanics)
- S6 Multiphysic coupling techniques / Application: thermal micro-actuator
- S7-S8 Model error estimation / Application: heated room with an open window (error estimation)
- S9-S10 Time- and frequency-dependent problems / Application: time-transient heating of a room and acoustics
- S11 Final exam

Class components (lecture, labs, etc.)

S1 to S10: lecture 1h30 + numerical tutorial on Comsol 1h30, except session 6 (3h tutorial)
off-class: project on multiphysics simulation (sensor, actuatore, physical phenomenon...) in groups of 4

Grading

2-hr written exam (1h theory + 1h practical on simulation tool): 65% of the final mark
Project evaluation as a continuous assessment: 35% of the final mark

Course support, bibliography

Textbook

Resources

Instructor: Guillaume PUEL

Tutorial classes: 35 students
Software: Comsol Multiphysics (Structural mechanics, MEMS)

Learning outcomes covered on the course

1. Solve and model a multiphysic problem including solid mechanics, heat transfer, fluid mechanics, electricity, and magnetism
2. Design sensors and actuators thanks to the use of different coupled physics and technologies
3. Model and solve a multiphysic problem using a commercial finite element code with specific attention to solution accuracy.

Description of the skills acquired at the end of the course

The validation of the milestones 2 of the skills **C1** and **C6** is related to the project made off-class in groups.
The validation of the milestone 2 of the skill **C2** is related to the final mark for this course.

2EL1860 – Building the city - town planning, architecture and engineering

Instructors : **François Cointe, Frédérique Delmas-Jaubert**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

Raise awareness among students about the problems of building the city: what do we build and for whom?

- To master the fundamental concepts and role plays of the construction through case studies, as well as the tools of the engineering at the service of the act of building and to make want to deepen in more detailed courses
- Introduce them to the diversity of trades necessary for the act of building
- Make them aware of the scientific and technical barriers that limit value creation

Quarter number

SG8

Prerequisites (in terms of CS courses)

none

Syllabus

Introduction to main challenges of the cities facing the climate evolution + choice of the territory to be studied.
2 and 3 : history of Paris and Grand Paris, by François Cointe
4 : urban and architectural visit
5 : Grand Paris Express, works of the century
6 : cities climate, means of action
7 : public spaces and adaptation to climate change
8 : urban engineering and urban services
9 : report delivery for territorial studies
10 and 11 : architecture, real estate and private stakeholders

Class components (lecture, labs, etc.)

Lessons + in situ lessons (visits)

Grading

Students are graded on a case study carried out mainly in tutorials, including assessment of attendance and participation in tutorial sessions + architectural study of a building.

Course support, bibliography

Institut Paris Région https://www.institutparisregion.fr/documents-historiques-de-reference.html
APUR–Atelier Parisien d'URbanisme https://www.apur.org/fr
Pavillon de l'arsenal–espace d'exposition de la Ville de Paris sur l'architecture et la ville https://www.pavillon-arsenal.com/
Cité de l'architecture et du patrimoine https://www.citedelarchitecture.fr/f

Resources

Team : François Cointe, Ulisse Vizzardi, Louis Massonet, Didier Lourdin, Olivier Ledru, Frédérique Delmas Jaubert

Learning outcomes covered on the course

At the end of this lesson, the student will be able to:

1. Know and understand the main paradigms of the construction of the city
2. Identify the economic and non-economic stakeholders of a construction project and its challenges
3. Distinguish the principals, funders, designers, builders, and operators
4. Know and understand the associated value chains of real estate, construction and urban services
5. Compare the positions of the main companies in the sector and their innovation logic

2EL1910 – Fundamental laws of the Universe: particle and gravitation physics

Instructors : **Christophe Yèche, Samira HASSANI**
Department : **DÉPARTEMENT PHYSIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **No**

Description

This course is an introduction to the four fundamental interactions: particle physics on the one hand and gravitational physics and cosmology on the other, from both theoretical and experimental points of view.

Quarter number

SG8

Prerequisites (in terms of CS courses)

None

Syllabus

A. Particle physics

A.1 Historical introduction to elementary particles
A.2 Special relativity and relativistic dynamics
A.3 Fundamental Interactions
A.4 Standard model of particle physics

B. Gravitation

B.1 General relativity: principle of equivalence, equation of motion, Einstein equation
B.2 Cosmology: geometry and expansion of the Universe, thermal history, structure formation (CMB), dark matter, dark energy
B.3 Example of an observational cosmology project: DESI, study of dark energy and gravitation, selection of quasars, tomography of the Universe with quasars

Class components (lecture, labs, etc.)

Seven one-and-a-half-hour lectures on particle physics and seven one-and-a-half-hour lectures on gravitation and cosmology. Five tutorials of one and a half hour.

Grading

The evaluation will combine a final test [75% of the grade] and several equally-weighted continuous tests, the average of which follows the rule set out in the RDE [25% of the grade].

All skills will be assessed in both types of testing. But more specifically, C2-1 skills will be tested mainly in the final exam, while C1-2, C2-3 and C6-3 skills will be tested in the continuous assessment and during the guided work sessions.

Course support, bibliography

Videos, course slides, written materials and also bibliographical references distributed during the course.

Resources

The classes will be lectures in French that will end with exercises counting as continuous assessment. Slides and written material in English will be made available.

Learning outcomes covered on the course

- get familiar with concepts of elementary particle and fundamental symmetry
- master the concepts of spacetime and quadrivector
- identify the relevant inertial referentials in a problem and control Lorentz transformations.
- Understand the difference between conservation and invariance and how to apply energy-momentum conservation in space-time.
- master the basics of tensor algebra with Einstein's notations
- calculate relativistic corrections for the Global Positioning System
- introduction to cosmology

Description of the skills acquired at the end of the course

C1.2 - Know how to use a model presented in the lecture in a relevant way
C1.3 - Develop a numerical simulation
C2-1 - Deepen this knowledge in particle physics and cosmology
C6-3 - Process particle physics and astrophysics data -

2EL1920 – Advanced Quantum and Statistical Physics

Instructors : **Jean-Michel Gillet**
Department : **DÉPARTEMENT PHYSIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

This course is both the continuity of the first year course and its complement.
It allows us to come back to certain aspects which, due to lack of time, have been covered too superficially for an effective use and to improve the understanding of a selection of basic concepts. It will be an opportunity to discuss the statistical physics of open systems (grand-canonical ensembles) and quantum statistics (bosons and fermions). Links will be established with the basis of Hamiltonian (and Lagrangian) mechanics. The course also aims to offer an extension to the quantum physics of atoms and molecules. The last sequence will give a brief introduction to quantum intrication.

Quarter number

SG6

Prerequisites (in terms of CS courses)

Prerequisite is:

The first year course on Quantum and Statistical Physics

Syllabus

We will discuss a selection of topics among which (non-contractual):
Basics of Lagrangian and Hamiltonian mechanics
Complements on the quantum harmonic oscillator
Complements on kinetic moment
Statistical physics of open systems
Quantum statistics
fermions
bosons
Fine and hyperfine structure of the atom
Variational theorem
The N-electron atom
Structure and properties of the atomic nucleus
Aspects of Quantum Molecular Physics
Quantum intrication and Bell inequalities

Class components (lecture, labs, etc.)

Lectures, exercises, reading and computer project

8 lectures
1 seminar (3h).
9 exercices/projects

Grading

A written test (1h30) whose questions relate potentially to the entire program and which allows in particular to evaluate the knowledge, the mastery of the methods set out above and the associated skills.
Competence C1, milestone 2 will be tested by means of the numerical project and an associated question during the final exam.

Course support, bibliography

The textbook is “Application-Driven Quantum and Statistical Physics” (Vol. 1, 2 & 3, World Scientific). Additional references will be given.

Resources

Teaching staff (instructor(s) names): F. Bruneval, M. Ayouz, E. Klein, J-M Gillet
· Maximum enrollment (default 35 students): 100
· Software, number of licenses required: Python and GAMESS
· Equipment-specific classrooms (specify the department and room capacity): small amphitheater for lectures, 3 rooms for tutorials

Learning outcomes covered on the course

At the end of the course, a student will be able to :
- justify the structure of the first rows of the periodic table aswell as the bonding mechanisms.
- decide the need for a quantum approach to temperature-dependent problems.
- differentiate a fermionic behavior from that adopted by bosons. He can then justify different components involved in response functions, such as specific heat, especially at low temperatures.
- propose a method of quantum modeling for some important properties of an ideal molecular gas but will know ways to take into account certain interactions.

Description of the skills acquired at the end of the course

The skills targeted are
C1.2 (milestone 1 or 2): Study a problem as a whole, the situation as a whole. Identify, formulate and analyse a problem in its scientific, economic and human dimensions
and C1.3 (milestone 1): Solve the problem with approximation, simulation and experimentation
Competences are tested by means of the numerical project and an associated question during the final exam

2EL2010 – Understanding, optimization and simulation of biotechnological processes

Instructors : **Filipa Lopes**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

Biotechnology is defined as "the application of science and technology to the transformation of materials by biological agents and enzymes to produce goods and services". Its fields of application are very broad and include many industrial applications, particularly in the health, food, waste treatment, energy production, cosmetics or pharmaceuticals sectors. Biotechnological processes are undergoing very strong development and recruitment.
The overall objective of course is to introduce the modern approaches to bioprocess engineering necessary to understand, improve, optimize and design innovative, competitive and more environmentally friendly bioprocesses.
In this context, the bioprocess will be addressed by a multi-scale (from the cell to the bioreactor) and multidisciplinary approach at the interfaces, guided by simulation and optimization tools. This course is located between transfer sciences, process engineering, physics and life sciences. The concepts covered in this course will be used for some other courses of the dominant (Life science, health and Environment, Energy,...) as well as in support of some Project Poles (Biotechnology and Health, Energy,...).

Quarter number

SG6

Prerequisites (in terms of CS courses)

Transport Phenomena (1A)

Syllabus

Microbiology :
- The cell;

- Microbial metabolism.

Principles of bioprocess engineering:
- The bioreactor;
- The implementation of a bioprocess;
- Studies of emblematic examples: methanisation, alcoholic fermentation, microalgae, activated sludge, etc.
- Operating modes;

- Mass transfer within the bioreactor.

Multi-scale modeling of the bioprocess:
- Macroscopic modeling ;

- Metabolic modeling ;
- Ownership of mass balance models;

- Calibration and validation of models.

Class components (lecture, labs, etc.)

General principles will be discussed and illustrated with industrial examples and applications during lectures and tutorials. The students will thus implement the knowledge acquired on practical engineering cases. In parallel, students will develop a project whose goal is to propose a bioprocess scheme for a given industrial application. Students, organised in groups, will apply their knowledge to a case study. They will choose a topic from among different biotechnological objectives. They will have to propose both processes, suitable microorganisms and implement a bioprocess model.

Grading

Final control (written) (65%) and oral presentation of the project by the team (35%).

Course support, bibliography

Presentations of the speakers and books (Madigan, M. (2007). Brock Biology of microorganisms; Doran, P. M. (1995). Bioprocess engineering principles. Academic press,...).

Resources

Teaching team (names of the teachers of the lectures): Filipa Lopes (Process Dep.) and Olivier Bernard (Biocore team, Inria).

Learning outcomes covered on the course

By the end of this course, the student will be able to:

- Explain the basics of living organisms functioning.
- Identify the phenomena (chemical, physical and biological) that occur within the bioreactor.
- Write the reaction network characterizing the main mass flows within the bioreactor, and adapted to the objectives of the model.
- Identify the mathematical expressions of the reaction kinetics associated with the reaction network.
- Study the main properties of dynamic bioreactor models (positivity of variables, boundarity, equilibrium, local stability).
- Calibrate a bioreactor model from experimental data.
- Propose a bioprocess scheme for a given application.

Description of the skills acquired at the end of the course

C1 - Analyse, design and implement complex systems made up of scientific, technological, social and economic dimensions

C2 - Acquire and develop broad skills in a scientific or academic field and applied professional areas

2EL2020 – Physics of divided matter

Instructors : **Hervé Duval**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

“God made solids, but surfaces were the work of the devil” (Wolfgang Pauli)
The behavior of dispersed media such as bubbles, drops, liquid films or colloids is strongly influenced by capillary and surface forces. Correlatively, body forces such as gravity play a secondary role. The present course focuses on dispersed systems with characteristic size ranging from 1 mm down to 10 nm.
These systems can be found everywhere around us. Applications concern biology (super-hydrophobic leaves, surfactant film in lungs, cavitation bubble made by a pistol shrimp), environmental science (dynamics of raindrops and their role in the biosphere, sediment siltation in estuaries), technology (fabrication of cosmetic and pharmaceutical emulsions, food industry, fire-fighting or insulating foams, surface treatments, lab-on-a-chip) and daily life (tears of wine, rising humidity and deterioration of houses and historical stone monuments). Numerous industrial innovations are based on the implementation and control of these systems.
The present course introduces the basic concepts of the physics of surfaces and addresses various interfacial phenomena encountered in dispersed systems: capillarity and wetting, colloidal interactions and Brownian motion, interface dynamics and associated instabilities. The role of interfacial energy in phase transformations (nucleation step) will be also discussed.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Transport phenomena (recommended)

Syllabus

The course is divided into three parts: 9 hours of **lectures and related tutorials**, 12 hours devoted to **case studies**, 9.5 hours dedicated to the realization of a **miniproject**.

Basic concepts (3 x (1.5h lecture + 1.5h tutorials))

1) Notion of surface tension
Physical origin
The thermodynamic and mechanical points of view
Capillarity: Laplace's law
Interfaces and boundary conditions of the Navier-Stokes equations
Area minimisation and minimum surfaces
Tutorial #1: Liquid menisci, capillary forces, wet hair and insects on water

2) Wetting
Ideal solid surfaces: Young-Dupré's law

Contact angle hysteresis
Influence of surface roughness
Influence of chemical heterogeneities
Towards superhydrophobic surfaces
Contact line dynamics
Tutorial #2: Modeling equilibrium contact angles on textured surfaces

3) Surfactants: equilibrium and dynamics
Amphiphilic molecules
Surface concentration and Gibbs adsorption equation
Micelles and critical micellar concentration
Dynamic surface tension and dynamics of surfactants
Interfacial rheology
Tutorial #3: Formation and drainage of a soap film

Case studies (4 x 3h)

Each case study offers the opportunity to examine physical phenomena of industrial or practical interest, to apply the concepts introduced in the lectures and to become familiar with state of the art modelling methods and mathematical tools. The case studies are carried out by groups of 3 to 4 students and supervised by a teacher. The duration of 3 hours per study allows each group to get to grips with the subject and to work on its own, with the methodological support of its supervisor. At the end of the 3 hours, each group reports its work in a note (handwritten or by word processing, as desired).

5) Capillary rise and imbibition
Applications: from raw sap rising in trees to the manufacture of composite materials
Equilibrium height in a vertical tube
Dynamics of capillary rise: inertial and viscous regimes
Capillary rise in a corner

6) Drainage and deposition of liquid films on a vertical flat plate
From anti-corrosion coatings on steel sheets to anti-reflective coatings on eyeglass lenses
Drainage of a liquid film
Dip coating
Scaling
Landau-Levich-Derjaguin theory: dynamic meniscus and asymptotic matching

7) Drop spreading
From coatings, inkjet printing to criminal investigations
Dynamic contact angle and contact line speed
Case of the perfect wetting: Tanner's Law
Influence of impact velocity on the maximum spreading diameter
The different impact regimes

8) Techniques to measure surface tension
This case study includes a practical work. It is carried out at the Laboratoire de Génie des Procédés et Matériaux (EIFFEL building, Univers Vivant). Two techniques for measuring surface tension are implemented and analysed in depth:
- The drop weight method (or stalagmometry)
- The pendant drop method.

Miniproject (7.5h+2h)

The mini-project is carried out in groups of 3 to 4 students. Each miniproject is part of a theme (related to the physics of divided matter) and focuses on a specific phenomenon, system or object. The student apply and deepen the various concepts previously discussed in class but also explore other aspects of the physics of divided matter. By way of example, here is a non-exhaustive list of themes chosen by students in previous years: The ascent of sap in trees, Pitfall traps of carnivorous plants, Marangoni bursting, Detergency and rolling-up, Leidenfrost effect, Droplet impact analysis in forensic science, Artificial water strider... Starting from the selected theme, each group has to

- address an issue,
- carry out and present a “kitchen experiment” to illustrate the theme and/or the problem
- identify the physical mechanisms involved in the focused problem
- optionally: design an experiment to investigate the problem, carry out a test campaign, analyze the experimental results and propose a simple model that accounts for the results OR develop a more complex model, implement it on the computer, run a parametric study and discuss the results.

The deliverables are :
- A ppt file that reports on the work done (the support of the oral presentation + appendices detailing the experiments, calculations, list of bibliographical references)
- A 20 min oral presentation with a demonstration of the code or a movie of the running experimental set-up, followed by 10 min of questions (duration adjusted for the number of groups)

Class components (lecture, labs, etc.)

The course is divided into three parts (see Contents for more details): 9 hours of lectures and related tutorials, 12 hours devoted to case studies (including 3 hours of practical work), 9.5 hours dedicated to the realization of a miniproject and its oral presentation.

Grading

Continuous assessment (mark out of 6, based on the notes delivered after each case study) + Course project (mark out of 14, based on ppt file + oral presentation + answers to questions)

Course support, bibliography

- Provided course material: lecture slides, problem statements and solutions
- References:

1. P.G. de Gennes, F. Brochard-Wyart and D. Quéré, Capillarity and Wetting Phenomena: Drops, Bubbles, Pearls, Waves, Springer, New York, 2004.
2. J. Israelachvili, Intermolecular and surface forces, Academic Press, Elsevier, 3rd edition, 2011.
3. E. Guyon, J.P. Hulin, L. Petit, Hydrodynamique physique, EDP Sciences, 3ème édition, 2012.

Resources

- Teaching staff (instructor(s) names): Hervé Duval, Marie-Laurence Giorgi, Jacopo Seiwert
- Maximum enrollment (default 35 student): 35
- Software, number of licenses: ImageJ (open source), python and the libraries scipy, matplotlib and numpy (open source)
- Equipment - specific classrooms (specify the department and room capacity): none

Learning outcomes covered on the course

At the end of this course, students will be able to:

- List and explain the mechanisms and physical phenomena involved in the most common dispersed systems, from industry or daily life;
- Define and calculate the associated characteristic length- and time scale;
- Interpret the dynamic behaviour of any dispersed system;
- Construct a model that captures the essence of the physical phenemona that take place in a dispersed system
- Propose an experimental setp-up/protocol to validate this model

Description of the skills acquired at the end of the course

C1.1 : Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem.
C1.2 : Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem.
C1.3 : Solve problems using approximation, simulation and experimentation.
C2.1: Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.

2EL2030 – Genomics and synthetic biology in health and industrial biotechnology

Instructors : **Behnam Taidi**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

The recent advent of high-throughput molecular biology techniques and the in-depth understanding of genetics based on advances in sequencing methods have overwhelmed medical and industrial biotechnology. In addition, synthetic biology (where novel biological and biologically based parts, devices and systems are (re)designed and constructed to perform new functions that do not exist in nature) has opened up a whole new field of opportunities where the engineers interact with biologists, chemists and computer scientists to conceive and make diagnostic and therapeutic devices.

A course is provided for the students to immerse themselves in the universe of genetics and synthetic biology where the latest concepts and industrial applications are unveiled and discussed.
The aim of this course is to teach the future engineer the structure, functioning and regulation of the genome and how this can be related to industrial and medical applications. In addition, by learning the nature of analogue signals and digital genetic data, the engineer will be able to choose the most pertinent methods for data processing and interpretation. This will transform the pool of information into informative knowledge that could be used for the provision of new products and services.
Thus, at the end of the course, students will have a strategic vision on how to progress in the field of genomics and synthetic biology: from the exploration of unprecedented data accumulation to the extraction of innovative knowledge and the transformation of the data into new rational and useful knowledge.

Quarter number

SG6

Prerequisites (in terms of CS courses)

1. Interest in Biology and modelling biological phenomena.
2. General notions of biology at the level of general knowledge.

Syllabus

- The syllabus consists of four modules; two of these are common foundation courses that pave the way for the subsequent two modules that focus on the application of synthetic biology to human health and the industrial biotechnology business.
- **Introduction:** Genome structure and regulation, cloning techniques, Synthetic Biology
- **Genomic analyses by high-throughput methods:** From genomic DNA to RNA
- **Human health applications:** Modifying and reprogramming the genome as a basis for gene and cellular therapy, based on stem cells and induced pluripotent stem cells (IPSC).

- **Industrial-Biotechnology applications:** Engineering the genome, the cellular chassis, allocation of resources, circuits engineering, metabolic engineering, the role of computer aided design in synthetic biology and metabolic engineering, introduction to iGEM

Class components (lecture, labs, etc.)

- The course module is organized in lectures, to introduce knowledge and methodological tools
- 28.5 hours of lectures
- Quizzes are included in the lectures covering the fundamentals.
- Attendance of the quizzes is obligatory, an unjustified absence will be considered a grade zero

Grading

- Continuous assessment for the lectures given by Marie-Anne DEBILY so attendance is obligatory for all these lectures that cover half of the course. The continuos assessment will count for 40% of the final mark for the first examination but not at all for the resit exam.
- Final written exam of 2 hours duration (no documents and no computer allowed) for the second half of the lectures.
- There are 4 evaluations during the lectures in total and each evaluation will count for 10% of the final grade.
- The final exam will count for 60% of the final grade

Course support, bibliography

Course slides available online

Resources

- Teaching staff (instructor(s) names): Behnam TAIDI (CS-LGPM), Marie-Anne Debily (Gustave Roussy), Jean Loup FAULON (INRA), Ioana POPESCU (University of Evry-val-d'Essonne), Matthieu JULES (AgroParisTech)
- Maximum enrollment : 40
- Equipment-specific classrooms : Computer room equipped with desktop (Linux or Windows OS) for a 4 hour module
- Continuous assessment for part of the course with a 2 hour final exam for the second half of the course. Attendance of the lectures covering the first half or the course is obligatory as they include the continous assement quizzez that will contribute to the final grade. Any non justified absences will count as a grade of zero and will therefore lower the average grade at the end of the course after the writen exam.

Learning outcomes covered on the course

On completion of the course, students should be able to:

- aware of technical tools and developments that enable to better understand how genomes are structured and have a control action
- understand the contributions of genomes to one's identity and understand the general principles that drive physiologic and pathologic immune evolution
- appreciate how genomic information can be used for developing improved therapeutics
- learn about the current status of stem cells and the new therapeutic developments
- have a strategic vision of the way to get ahead in the field of genomics: from data mining to the extraction of innovative knowledge

Description of the skills acquired at the end of the course

- C1.1. : Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem Milestone 1
- C1.2. : Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem Milestone 1
- C1.4. : Design, detail and corroborate a whole or part of a complex system. Milestone 1

2EL2040 – Process engineering: application to the environment and biomanufacturing

Instructors : **François Puel, Julien Colin**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

Process Engineering consists in d**esigning, operating and optimizing processes** for **the development of various products and services** in many traditional and high-tech sectors (agri-food, biotechnology, cosmetics, fine chemicals, materials, oil, pharmaceuticals, water and waste treatment, etc.) and for the production of traditional, low-carbon and renewable **energies**.
This course is an introduction to Process and Bioprocess Engineering and its methodologies. **The fundamentals of the course allow students to acquire general tools** that can be easily transposed to multiple fields.

The sustainability of processes is a major challenge.
Some processes are intrinsically key tools in the global **sustainable development** strategy at different scales (local and global), such as the **recycling and recovery** of many products and the **purification** of liquid and gaseous effluents.
Nevertheless, in general, **new processes must be developed and existing processes must be optimized (intensification)** in order to reduce the impacts of the industrial sector. The challenges associated with this environmental dynamic are multiple: reduction of energy and raw material consumption, costs, waste, risks and dangers.
In addition, **bioprocesses** have developed very strongly in the last decades for two reasons: (i) the use of living organisms, acting as processing plants, to transform matter, purify polluted systems (liquid, solid), (ii) the use of biomass to replace fossil resources.

This course is based on **concrete examples** (simplified in order to make them intelligible), allowing students **to apply and learn the fundamentals** of the course, while **focusing on processes oriented towards sustainable development**.
Some case studies are focused on bioprocesses used in **industrial and environmental biotechnology**. Bioprocesses are studied **at the industrial bioreactor scale**. The description and understanding of biological processes (metabolism, maintenance, etc.) at the cell level are not addressed. The biological agents are thus considered as cellular catalysts transforming raw materials into products according to given kinetic laws whose application **does not need any specific background in biology**.

Quarter number

SG8

Prerequisites (in terms of CS courses)

None

This course is not open to students having taken the analogous course during the ST5 period (2SC5210)

Syllabus

1. Introduction to Process Engineering for Sustainable Development; steady state material balance
<u>Case study:</u> Process for the production of 1st generation bioethanol (*conversion of renewable raw materials by white biotechnologies*)
2. Flow models (perfectly agitated and plug flow)
<u>Case study:</u>
Valorization of Whey (*Valorization of residues from the food industry by white biotechnology*)
Dimensioning of biological treatment tank basin of an urban wastewater treatment plant (*process in the service of the environment, reduction of reactor volumes and groundwater footprint*)
3. Thermal balances: calorific / enthalpic
<u>Case study:</u> Dimensioning of a vinification tank and its temperature control (*optimisation of the reactor geometry and its thermal regulation*)
4. Liquid-vapor balances equilibria, single and multi-stage distillation
<u>Case study:</u> Multi-stage distillation of bioethanol (*alternative to fossil fuels*)
5. Mass Transfer: Diffusion & Convection
<u>Case study:</u> Production in raceway of Spirulina Mocroalgae (*sustainable production of nutrient for food and feed*)
6. Mass Transfer: Permanent Contact Technologies
<u>Case study:</u>
Treatment of a gaseous effluent. Removal of a pollutant (*environmental process*)
Biogas purification for biomethane production by membrane technology (*production of a renewable energy carrier for conventional uses*)

Class components (lecture, labs, etc.)

The course module is organized in lectures (12h), to introduce knowledge and methodological tools, which will be then applied through case studies (13.5h). The pedagogical mode of the lectures (face-to-face or flipped classroom) will be decided collectively during the first lesson. The case studies will be conducted in class, except for the last one (homework). Two of the case studies will consist of mini-projects to be carried out by groups in autonomy.

Grading

Homework: Presentation, by group, of a literature survey whose topic is an extension of the course (40% of the grade); this presentation may take place either by an oral session of by a poster session take place .Individual final written exam: 2-hour case study (60% of the grade).

Course support, bibliography

- **Slideshows**

• **Techniques de l'ingénieur:**
+ Charpentier J., Génie des procédés, développement durable et innovation – Enjeux et perspectives, 2013
+ Moulin J.P., Pareau D., Rakib M., Stambouli M., Transfert de matière – Méthodologie, 2000
+ Moulin J.P., Pareau D., Rakib M., Stambouli M., Isambert A., Transfert de matière – Distillation compartimentée idéale, 2001
+ Moulin J.P., Pareau D., Rakib M., Stambouli M., Transfert de matière- Autres opérations compartimentées, 2002
+ Buch A., Rakib M., Stambouli M., Transfert de matière- Cinétique du transfert de matière entre deux phases, 2008
+ Sun L.M., Thonnelier J.Y., Perméation gazeuse, 2004
+ Vuillermaux J., Réacteurs chimiques – Principes, 1994
+ Boulinguiez B., Le Cloirec P., Purification de biogaz – Élimination des COV et des siloxanes, 2011

• **General Books:** Perry Chemical Engineer's Handbook, 8th edition, 2007, McGraw-Hill, New York

• **Specific books:**
- *<u>Reactor and bioreactor engineering</u>*
+ Coulson and Richardson's Chemical Engineering – Volume 3A: Chemical and Biochemical Reactors and Reaction Engineering, 4th Edition, 2017, Elsevier. Oxford
+ Fogler H.S., Elements of chemical reaction engineering, 5th Edition, 2016, Pearson Education, Englewood Cliffs
+ Levenspiel O., Chemical Reaction Engineering, 3rd edition, 1999, John Wiley and Sons, New York
+ Villadsen J., Nielsen J., Lidén G., Bioreaction Engineering Principles, 3rd Edition, 2011, Springer, New York

- *Heat and mass transfer*
+ Bergman T.L., Lavine A.S., Incropera F.P., Dewitt F., Fundamentals of Heat and Mass Transfer, 7th Edition, 2011, John Wiley and Sons, New York
+ Coulson and Richardson's Chemical Engineering – Volume 1B: Heat and Mass Transfer: Fundamentals and Application, 7th Edition, 2018, Elsevier, Oxford
+ Cussler E.L., Diffusion Mass Transfer in Fluid systems, 3rd Edition, 2009, Cambridge University Press, Cambridge
+ Treybal R., Mass Transfer Operations, 4th Edition, 1982, McGraw Hill, New York
- *Bioethanol production*
+ Cardona C.A., Sanchez O.J., Gutierrez L.F, Process synthesis for fuel ethanol production, 2010, CRC Press, Boca Raton
+ Naik S.N., Goud V.V., Rout P.K., Dalai A.K, Production of first and second generation biofuels: A comprehensive review, Renewable and Sustainable Energy Reviews 14, 2010, 578–597
+ Vohra M., Manwar J., Manmode R., Padgilwar S., Patil S. Bioethanol production: Feedstock and current technologies, Journal of Environmental Chemical Engineering 2, 2014, 573–584

Resources

Teaching staff (instructor(s) names):Francois PUEL / Victor POZZOBON / Cristian PUENTES / Julien COLIN
Maximum enrolment (default 35 students): 60
Software, number of licenses required: Excel, Python
Equipment-specific classrooms (specify the department and room capacity): None

Learning outcomes covered on the course

At the end of this course, students will be able to:

1. List the type of mass transfer and its coupling to heat transfer,
2. Identify the different mass transfer mechanisms (diffusion / convection) working in a given configuration and the potential coupling between heat and mass transfer,
3. Write mass balances, taking into account, if necessary, chemical or biochemical reaction kinetics,
4. Simplify a seemingly complicated problem, where several transfer phenomena coexist, by taking into account only the main ones,
5. Formalize phenomena into equations through elemental balances,
6. Design conversion and separation technologies based on thermodynamic and kinetic considerations.

Description of the skills acquired at the end of the course

- C1.2: Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem. **Milestone 2**
- C1.3: Solve problems using approximation, simulation and experimentation. **Milestone 1**
- C2.4: Create knowledge within a scientific paradigm. **Milestone 2**
- C7.1: Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. Highlight the added value. **Milestone 2**
- C7.2: Persuade through interpersonal relations to understand the needs and expectations of multiple participants in a dialogue, elicit reactions and create a climate of trust. **Milestone 2**

2EL2140 – Strategy, Marketing and Organization

Instructors : **Éléonore MOUNOUD**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **Yes**

Description

This course allows students to implement in a relevant and reasoned way the principal models of strategy and marketing. It develops the notion of business model and how to use it to account for past and future transformations of businesses and companies. The strategic issues related to the development of services, the globalization of value chains, and innovation are thus addressed through case studies. The societal challenges of digital transformation and ecological transition as well as their impact on business models will also be addressed (circular economy). The course invites the students to a personal reflection on the complementarity but also the rivalry between these two transitions based on case studies presented by lecturers on the digital transition, the energy transition and the scarcity of resources (sobriety principle).

Quarter number

SG6

Prerequisites (in terms of CS courses)

Business management course: PESTEL analysis, SWOT analysis,, shareholders, CSR
Start up Week :business model canvas

Syllabus

1. Introduction to marketing
2. introduction to strategy
3. Nespresso case study / detail of business model components
4. Conference on Global Coffee Sector Analysis / Globalization of CGV Value Chains / Social Costing
5. Case Study Michelin Solutions / Strategies in Services / TCO Calculation / Functionality Concept
6. SKF Case Study / Understanding B to B Marketing and Globalization
7. Tesla case study / innovation management
8/9/10. WORKSHOP Business for Climate Convention (40 students) / Quantification of business models EY Parthénon (80 students)
11. Oral defense
12. Written exam

Class components (lecture, labs, etc.)

lectures 8 hours
case studies 10 hours
conferences 6 hours

workshop 9 hours
written exam 2 hours, oral exam 1 hour

Grading

Preparation of the sessions (5 reading notes prior to the case studies),
Assessment: participation in case studies (30%), workshop deliverables (30%), written exam (40%)

Course support, bibliography

Strategor

Resources

Eléonore Mounoud, responsable du cours
Marie France Crevecoeur, Head of Professional Services and Solution Delivery chez Philips, chargée de cours

1. Fedi Soyah manager at EY Parthenon

Alexis Treilhes, Green insiders
Alain Honnart, ex directeur industriel Vallourec, directeur Métal Value

Learning outcomes covered on the course

At the end of this course, students will be able to:
• Formulate the positioning and value proposition of a company to its customers
• Detail the business model of a company and to diagnose its coherence
• Identify the challenges of internal or external transformations (transitions) relevant to a company and how to respond to them
• Define a logic of transformation of a company (services, innovation, globalization, transitions) towards a more sustainable model

Description of the skills acquired at the end of the course

CentraleSupelec competences:
C4.1 :Think in client terms, identify and analyse customer needs, the constraints of other stakeholders including societal challenges.
C4.2: Know how to identify the value that a given solution affords a client and the market. To be able to detect opportunities and seize them.
C9.2,: Identify, within a given structure, the scope of liability as well as socio-ethical an environmental responsibilities.
C9.4 : Demonstrate rigour and critical thinking in approaching problems from all angles, be they scientific, social or economic.

2EL2150 – Corporate finance and Law

Instructors : **Maxime Guymard, Valérie Feray**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **Yes**

Description

The course goes into law and finance in depth after the first and second-year introductory course. It also gives an opening on various Finance/Law professions via speakers working for different business companies (financial consultaing, audit, Innovation & Intellectual Property Director, IP attorneys, attorneys-at-law).

Quarter number

SG6

Prerequisites (in terms of CS courses)

Business Management (1st year), Introduction to Corporate Finance (1st year), Introduction to Law (2nd year)

Syllabus

The discussed subjects of this course will be divided in 3 parts: one third in Law, one third in Corporate Finance, one third in both Finance and Law.

Law
Themes of lectures:

- Labor law
- Introduction to corporate law
- Patentability, patent prosecution and related costs

Software protection

Finance

Themes of lectures:

- In-depth study of accounting basics: balance sheet, income statement (P&L), cash flow statement
- Solvency
- Profitability (ROCE, ROE)
- Weighted Average Cost of Capital (WACC)
- Financial criteria to select an investment (NPV, IRR)
- Business Valuation
- Start Up financial management
- Bankruptcy and restructuring
- Introduction to Market Finance (stocks, bonds, derivatives)

Class components (lecture, labs, etc.)

Lectures (13 * 1:30) | Tutorials (6 * 1:30) | Final Exam (2 hours : Finance 1h + Law 1h)

Grading

Final written exam (100% of final mark)

Resources

• **Teaching staff** (instructor(s) names)

<u>Law</u>
Valérie FERAY (main lecturer - Founder and managing partner - IPSILON)
Pierre-Jacques CASTANET (speaker and teaching assistant - Partner at In Extenso - attorney-at-law specialized in labour law)
Mélanie COIRATON (Speaker and teaching assistant - Partner at Racine - Attorney-at-law)
Mardson McQUAY (speaker and teaching assistant - Senior IP Attorney - King Abdullah University of Science and Technology)
Ghislain DEMONDA (speaker and teaching assistant - Patent Attorney - API Conseil)

<u>Finance</u>
Maxime GUYMARD (main lecturer)
Jean-Baptiste MONLOUIS (teaching assistant – KPMG)

- Louis-Arthur HUIGNARD (teaching assistant – KPMG),
  • **Maximum enrollment** (default 35 students): 105 max for the course (35 students for 3 tutorial groups)

Learning outcomes covered on the course

- **In Finance:**

- Know how to read and interpret the financial statements of a company (balance sheet, income statement, cash flow statement)
- Evaluate the profitability and solvency of a company
- Know the financial criteria for making an investment decision
- Understand the basics in Market Finance (stocks, bonds, dérivatives)
- Know the different professions in Finance

In Law:

- Labour law : learn the basics as employer and employee **(this 3-hour course+tutorial will be exceptionnally held in French - an English abstract will be provided for non-French speaking students)**
- Introduction to corporate law : The benefits of using the coporate form - Definition of the company - Classification of companies - the Key actors - Financial matters - The main stage in a company's life
- Patentability, patent prosecution: learn which subjects can be protected by patents, how to assess the prior art to determine patentability, the prosecution steps from filing up to grant of a patent
- Software: learn the basics and various protection solutions, the pros and cons of each of them and the corresponding pitfalls

Description of the skills acquired at the end of the course

- C3- Act, undertake, innovate in a scientific and technological environment
- C4 - Have a sense of value creation for his company and his customers

2EL2160 – Environmental economics, energy and sustainable development

Instructors : **Vincent Rious, Pascal DA COSTA**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **Yes**

Description

The objective of the "Economics of the Environment, Energy and Sustainable Development" course is to address:

i) the major environmental issues of the 21st century and the human factors that structure them (demography, economy, development, etc.);
(ii) the main theories in the field that have, in particular, founded economic principles that must be adopted in response to these issues (optimal carbon tax and environmental taxation, fight against negative externalities, etc.);
(iii) economic and regulatory policies in practice, both at the environmental and energy levels (European energy-climate packages, low-carbon electricity mix, etc.);
iv) the ecological and climatic transition strategies of the major structuring energy sectors in France and Europe (electricity, transport, hydrogen, etc.), thanks to the intervention of specialists and experts in the field, capable of: 1. presenting both physical and economic orders of magnitude; 2. in a vision that is both prospective and multidisciplinary.

Course outline :

1. The major challenges of decarbonisation of the economy at the global level
2. General principles of environmental economics on decarbonation and biodiversity (ecosystem services), and environmental accounting and fiscal systems
3. The return of energy systems planning. Illustration by forecasting balances and ten-year network development plans in the gas and electricity sectors
4. Changes in the energy system. Focus on the electricity system (opening to competition and the shift towards energy transition)
5. The dark side of the French decarbonisation policy
6. The challenges of decarbonising consumption
7. Gas in the energy transition

Quarter number

SG8

Prerequisites (in terms of CS courses)

Common economics course.

Syllabus

- Origins of economic growth and effect on the "unavailability" of natural resources (end of cheap oil, etc.)
- Economic models for the optimal management of renewable and non-renewable natural resources
- Demographics: changing world populations
- Climate: greenhouse effect and climate change
- Resource management issues (reserves, distribution, prices): resources for energy (oil, gas, coal, uranium), raw materials (ores), water
- State of the art and new technologies for energy, in a vision that is both prospective and multidisciplinary.

Class components (lecture, labs, etc.)

Amphitheatre / Tutorials

Grading

Evaluation in project mode / academic articles work: **the last 3 class slots are scheduled for assessment and all students must be present.**

Course support, bibliography

Slide shows, various multidisciplinary books and economic articles.

Resources

Course in French.

Learning outcomes covered on the course

- Know the key figures (state of play and scientific forecasts) that are the subject of so much debate in the media when they involve stakeholders in an environmental conflict, for example industrialists and ecologists.
- Understand the assumptions and models on which these figures are based.
- Raise awareness of the coupling of resources, energy, environment, climate, economy, geopolitics, demography.
- Raise awareness at different levels: local to global.
- **A course on the Sustainable Development Goals.**

Description of the skills acquired at the end of the course

C1.1 Examine a problem in its full scope and depth, within and beyond its immediate parameters, in order to understand it as a whole. This set links the scientific, economic and social dimensions of the problem.

C2.1 Master a field or discipline based on the basic or engineering sciences.

C4.1 Think in terms of customers, identify and analyse customer needs, other stakeholder constraints and societal challenges.

C9.4 Demonstrate rigour and critical thinking by approaching problems from all angles, scientific, human and economic.

2EL2170 – Economics of growth and innovation

Instructors : **Mehdi SENOUCI**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **Yes**

Description

Economic growth, in a broad sense, is a concept that refers to all economic changes over time. One of the strongest consensuses in economics is that which links growth to innovation. The first objective of the course is to make students aware of the study of economic growth, both long and short term, by trying to convince them that the regularities as well as the paradoxes of growth justify an analytical approach combining the exploration of facts, empirical analyses and theory-building. The second objective is to present the great economic evolutions of the world from the origins to the present day, with greater importance given to the modern era, as well as the theories related to each era and each transition. The third and more diffuse objective is to push students to question the future consequences of innovations currently underway or in the making. The course will combine theory and empirical studies following the red thread of history.

The course is demanding and research-oriented, and is intended for students who are willing to invest themselves. It is strongly discouraged for students leaving in S8. In addition to the final exam, two assignments will be expected (one of which will be handed in during the tutorials) that will involve constructive reading of research articles.

Quarter number

SG6

Prerequisites (in terms of CS courses)

Economics compulsory course. Basics of econometrics (ordinary least squares).

Syllabus

1 - Economic growth as a historical phenomenon: the major trends
2 - A detour: the neoclassical model of perfect markets
3 - Neoclassical analysis of growth: successes and failures
4 - Growth, energy and the environment
5 - Technology, labor, and inequality
6 - Economic growth over the very long run
7 - The future of economic growth

Class components (lecture, labs, etc.)

Lectures (19.5h), Tutorials (9h), Exam (2h)

Grading

One mandatory assignment in tutorials: 1/3
One other mandatory assignment: 1/3
Final exam: 1/3

Course support, bibliography

- Course slides
- The course will not rely on a specific textbook, but students can refer to:
    - Hal R. Varian (2014) *Intermediate microeconomics - A modern approach,* W. W. Norton & Company, 9th edition
    - Robert J. Barro & Xavier Sala-i-Martin (2003) *Economic Growth*, MIT Press, 2nd Edition
    - David N. Weil (2012) *Economic Growth,* Pearson Education
    - Charles I. Jones & Dietrich Vollrath (2013) *Introduction to economic growth,* W. W. Norton & Company, 3rd edition
- Many articles and books will be covered, including:

a. Acemoglu, Johnson, and Robinson (2001) "The Colonial Origins of Comparative Development: An Empirical Investigation." American Economic Review.
b. Acemoglu, Johnson, and Robinson (2002) "Reversal of Fortune: Geography and Institutions in the Making of the Modern World Income Distribution." Quarterly Journal of Economics.
c. Aghion, Dechezleprêtre, Hémous, Martin and Van Reenen (2016) ‘‘Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry,’’ Journal of Political Economy.
d. Ashraf and Galor (2013) "The `Out of Africa' Hypothesis, Human Genetic Diversity, and Comparative Economic Development," American Economic Review.
e. Clark (2007) *A Farewell to Alms: A Brief Economic History of the World*, Princeton University Press.
f. Comin and Mestieri (2014) ‘‘Technology Diffusion: Measurement, Causes and Consequences,’’ Handbook of Economic Growth.
g. Diamond (1997) *Guns, Germs and Steel: The Fates of Human Societies,* W. W. Norton & Company.
h. Galor (2005) "From Stagnation to Growth: Unified Growth Theory," in Handbook of Economic Growth.
i. Galor and Ozak (2016) "The Agricultural Origins of Time Preference," American Economic Review.
j. Greenwood Hercowitz and Krusell (1997) "Long-Run Implications of Investment-Specific Technological Change," American Economic Review.
k. Habakkuk (1962) *American & British Technology in the 19th Century: The Search for Labour-Saving Inventions*; Cambridge University Press [2nd edition: 1967].
l. Kaldor (1961) "Capital Accumulation and Economic Growth," in The Theory of Capital (F. A. Lutz & D. C. Hague, eds.); Macmillan, St. Martin's.
m. Mankiw, Romer, and Weil (1992) "A Contribution to the Empirics of Economic Growth." Quarterly Journal of Economics.
n. Nordhaus (1973) "The Allocation of Energy Resources," Brookings Papers on Economic Activity.
o. Piketty and Zucman (2014) "Capital is Back: Wealth-Income Ratios in Rich Countries 1700-2012," Quarterly Journal of Economics.
p. Romer (1990) "Endogenous Technological Change." Journal of Political Economy.
q. Solow (1956) "A Contribution to the Theory of Economic Growth," Quarterly Journal of Economics.
r. Solow (1957) "Technical Change and the Aggregate Production Function," Review of Economics and Statistics.

Resources

Lectures (Mehdi Senouci)
Tutorials

Learning outcomes covered on the course

At the end of this course, students will be able to:
- Model consumption, production, exchange and technical change with neoclassical models;
- Know, manipulate and interpret different theoretical models of economic growth;
- Discuss the issues of growth in an analytical logic and in knowledge of the history and facts of economic growth.

Description of the skills acquired at the end of the course

Model consumption, production, exchange and technical change with neoclassical models; is included in skills **C1.3 "Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation"**, and **C2.3 "Rapidly identify and acquire the new knowledge and skills necessary in applicable / relevant domains, be they technical, economic or others."**
Know, manipulate and interpret different theoretical models of economic growth; is included in skills **C1.1 "Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem", and C2.3 "Rapidly identify and acquire the new knowledge and skills necessary in applicable / relevant domains, be they technical, economic or others."**
Discuss the challenges of growth in an analytical logic while being aware of the history and facts of economic growth; is included in skill **C7.1 "Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. Highlight the added value".**

2EL2190 – Sober and sustainable innovation

Instructors : **Éléonore MOUNOUD, Juliette WEBER**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **No**

Description

Innovation poses significant and multiple managerial challenges for companies. On the one hand, many companies find it difficult to innovate, because their organisation, which is the basis of their successful business model, is also a brake on innovation, which is why Innovation Departments have been created alongside R&D, Marketing and Strategy Departments. On the other hand, even more start-ups are exploring and experimenting with new business models, in order to find out what is valuable for the customer, how to deliver this value, and how to make money while doing so.

This course aims to explore in a concrete way the managerial and societal challenges posed by innovation in a world in crisis (health, climate, social, economic, financial ...). Therefore it is organised in two parts

- conferences and testimonies on the challenges of innovation where you deepen your knowledge of the challenges of transformation (Digital, Carbon, Impact) and you translate them into opportunities / threats to face and strengths to develop (weaknesses to overcome) for the innovation you will be asked to study

- working sessions where you develop your analysis in a team and in an iterative way to diagnose the innovation you are studying and propose development recommendations for a Sufficiency and/or Solidarity-based innovation.

Quarter number

SG8

Prerequisites (in terms of CS courses)

This course is a "Discovery tour" of Innovation Management and Business creation, therefore there is no prerequisite other than the common 1st year Business Management course. For students who have not taken this course, a document will be provided at the beginning of the course to introduce them of the key concepts, and a MCQ will be offered halfway through the course to validate their knowledge.

Syllabus

Conferences on the challenges of innovation to learn about the challenges and methods of innovation management

on strategies based on disruptive innovation
- in 2023, Erwan Pannier founder of Spark - hydrogen production by plasma
on innovative design methods, CK theory, TRIZ and agile method
- in 2023, Rodolphe Rosier - the Axane case and innovation in maritime transport
on the challenges of transition and adaptation
- in 2023, Eric Bergé, industry transformation plan (PTEF, Shift project)

on financing and impact investing
- in 2023, Anita de Voisins - financing and impact investing - Investir&+

Practical sessions per class of 30/40 students (i.e. 3 classes organised in 6 groups of 5 per class) either on a mini-project or on several case studies (diagnosis and recommendations). Each class has a specific theme and a different leader
- Juliette Weber on circular and social innovation and/or territorial resilience (cases Enercoop, Envie, Commown ...)
- Robin Armant on low tech (Atelier Paysan, Neoloco, Thoreme, ...)

Class components (lecture, labs, etc.)

Courses / Conferences
Practical sessions: weekly assignements
Mini project

The course represents about thirty hours of courses or conferences (HPE) and requires approximately the equivalent in preparation for the business case (to be delivered).

Grading

Assignments and oral defence of the mini-project (40%)
Final exam - 2-hour MCQs on the lectures (40%)
Participation 20%.

Course support, bibliography

Course materials on Edunao: documents, lecture materials, video

Managing Innovation: Integrating Technological, Market and Organizational Change, Joe Tidd and John Bessant. WILEY, June 2018 608 Pages,

Lean Startup, Eric Ries
Business Model Canvas, Alexander Osterwalder
Startup Owners Manual, Steve Blank & Bob Dorf
Get Going, Guy Kawasaki
Guide pratique de la levée de fonds, Jean-François Galloüin
The Founder's dilemnas, Noam Wasserman

Learning outcomes covered on the course

At the end of the course students will be able to :
- understand what innovation entails for Sufficiency and Solidarity
- identify what innovation is,
- decide whether a first job as innovator, intrapreneur, etc. could be an option for them.
- apply methods linked to the development of new activities : Lean startup, Business Model Canvas, LaunchPad Toolkit, etc.

Description of the skills acquired at the end of the course

We will work mainly on skills:
C3 - Act, Undertake, Innovate
C4 - Have a sense of value creation for your company and for your customers

By presenting cases in a concrete way
By providing methodological frameworks

2EL2210 – Operations and supply chain management

Instructors : **Guillaume LAMÉ**
Department : **DÉPARTEMENT GÉNIE INDUSTRIEL ET OPÉRATIONS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **No**

Description

This module provides an introduction to challenges in the management of operations and supply chains. It explores decisions involved in designing, planning and piloting production and distribution systems, both for goods and services. The main challenge in these systems is to ensure that the right product or service is delivered at the right place and the right time, in the quantity and at the quality required by the customer, while making efficient use of resources.

In this context, it is crucial to understand industrial systems at different levels (supply chain, factory, warehouse, workshops, machine), to identify processes, to assess economic and environmental challenges and to develop quantitative and qualitative methods and tools to improve the performance of these systems.

Examples will be drawn from various industrial sectors.

Quarter number

SG8

Prerequisites (in terms of CS courses)

none

Syllabus

This module will explore:

• The organisational dimension of production and distribution systems
• The performance of production systems through different perpectives
• Qualitative and quantitative methods aimed at improving the performance of production and distribution systems
• The implementation of these approaches, including feasibility, adaptability, limitations and change management

Class components (lecture, labs, etc.)

Lectures and applications on exercises and study cases. Part of the content will be as reading assignments and videos to study individually before classes.

Grading

a project ti submit and defend (40%) and a final written exam of 2 hours (60%)

Course support, bibliography

Lecture slides and notes, videos, study cases and exercises.

Textbooks:
Slack N, Chambers S, Johnston R. Operations management. 5. ed. Harlow: Prentice Hall/Financial Times 2009.
Holweg M, Davies J, Meyer Ad, et al. Process theory : the principles of operations management. First ed. Oxford: Oxford University Press 2018.
Chopra S, Meindl P. Supply Chain Management. Strategy, planning and operation. 5th. ed. New York, NY: Pearson Education 2012.

Resources

- Lectures, case studies, testimonies from professionals

Learning outcomes covered on the course

• Diagnose issues and to assess performance in industrial operations systems.
• Select the relevant fundamental tools and concepts to improve the performance of operations and supply chains.

Description of the skills acquired at the end of the course

This course will address the following competencies:

- C1 Analysing, designing and realising complex systems with scientific, technological, human and economic components
    - C1.2 Using and developping relevant models, choosing the righjt modelling scale and simplifying hypotheses to address the problem
    - C1.3 Resolving the problem through approximating, simulating and experimenting
    - C1.5 Leveraging a broad scientific and technical knowledge base in a transdisciplinary effort
- C2 Developing specific knowledge of a scientific or industrial domain et a professional domain
    - C2.1 Exploring a scientific or engineering domain or discipline
- C4 Understanding value creation for organisations and their clients
    - C4.1 Being customer-oriented. Identifying/analysing needs, stakes and constraints for other stakeholders, including on a social and economic level.
    - C4.2 Identifying the value created by a solution for a client and the market. Being able to identify opportunities and seize them.

2EL2220 – Organizational and market theories

Instructors : **Yannick PEREZ**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **No**

Description

The object of this course is the analysis of organizations, based on the tools of the enlarged microeconomics. Like other fields of application in economics, Organizational economics has experienced sustained development over the past 20 years. The economics of organizations involves the use of economic analysis and its methods to understand the existence, nature, 'design' and performance of organizations. The economic analysis of organizations is carried out in comparison with the markets and it covers, beyond the firm, organizational forms of great diversity (unions, social movements, agencies, schools, ...).

Quarter number

SG6

Prerequisites (in terms of CS courses)

This course is given only in French, and all the materials are also in French.

Syllabus

1. Introduction
2. Chapter 1: Diversity of modes of organization in a market economy

    a. Markets as a structuring mode of production and trade
    b. Integrated organizations and the nature of the firm.
    c.. Hybrid forms

3. Chapter 2: Modes of coordination

    a. Information processes
    b. The role of contracts

4. Chapter 3. Incentives and motivations

    a. Incentives: basic models
    b. Incentives linked to the properties of the modes of organization

5. Conclusion

Class components (lecture, labs, etc.)

The course is made up of two parts:
A first where the tools of economic theory of organizations are presented.
The second where they are implemented by student group projects working on typical situation in terms of Economics of organization

Grading

The assessment consists of two exercises.
The first is a presentation of a typical situation in a student group. This work represents 60% of the final grade.
The last is a table assignment composed of 4 questions on the essential concepts of the course. This work represents 40% of the final grade.

Course support, bibliography

Brousseau Eric – Glachant Jean-Michel, New Institutional Economics A Guidebook CUP Press.
Gibbons Robert & Roberts John, The Hanbook of Organisational Economics, Princeton.

Resources

Students must come with their laptops.
This year only one group will be open for 33 students.

Learning outcomes covered on the course

- Understand the challenges of creation, development and operation of economic organizations.
- Acquire the tools of contract theory
- Find out how to build incentives and coordinate teams
- Understand the determinants of the choice of organizational forms adapted to economic activities.

Description of the skills acquired at the end of the course

At the end of this course, the students will understand why economic organizations work or not.
They will understand the problems of hierarchical management, principal agent, moral hazards and adverse selection. They will have analyzed incentive and remuneration systems and will have analytical tools to understand inter-industry relationships.

2EL2230 – Maintenance and Industry 4.0

Instructors : **Zhiguo ZENG**
Department : **DÉPARTEMENT GÉNIE INDUSTRIEL ET OPÉRATIONS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

This course provides a solid culture on the concepts, methods and tools involved in the implementation of a predictive maintenance approach.

Predictive maintenance is one of the pillars of Industry 4.0. It is based on the use of data collected online, their processing and their integration into dynamic decision-making processes. It also relies on the provision of connected agents capable of performing tasks in real time and optimizing their management. Concretely, it is about anticipating failures, shutdowns, accidents in production processes or service systems and planning at best replacement, renewal, return to service operations, etc.

The objective of this course is to give future decision-makers the necessary culture to design, model and recommend predictive maintenance strategies. Emphasis is placed on data-driven approaches and probabilistic or statistical models that apply to any industrial system. This background should allow effective interaction with engineers "business" very close to applications and "data scientist" in charge of data processing

Quarter number

SG8

Prerequisites (in terms of CS courses)

Basic knowledge in probability and statistics, data analytics, modeling and optimisation

Syllabus

- Course introduction; Project introduction;(1.5h)
- Fault detection and diagnosis through machine learning (9h)
- Planning maintenance activities through optimization (9h)
- Predictive maintenance (9h)
- Project Defense (2h)

Class components (lecture, labs, etc.)

- 14.5h of lectures and 14h of tutorials with practical implementations of the models.
- Possibility to have a proportion of the lecture in inverse class.

Grading

Examination with use case (2h, 50%) + Course project (50%)

Course support, bibliography

Bibliography

- System Reliability Theory, Models, Statistical Methods and Applications, Marvin Rausand, Anne Barros, Arnljolt Hoyland, 2020, Third Edition, Wiley
- Degradation Processes in Reliability, Waltraud Kahle, Sophie Mercier, Christian Paroissin, John Wiley & Sons, 2016
- Maintenance, Replacement, and Reliability: Theory and Applications, Second Edition (Mechanical Engineering) 2nd edition by Jardine, Andrew K.S., Tsang, Albert H.C. (2013) Hardcover
- Case Studies in Reliability and Maintenanc, Wiley Series in Probability and Statistics, Wallace R. Blischke, D. N. Prabhakar Murthy, John Wiley & Sons, 2003
- Reliability and Optimal Maintenance, Hongzhou Wang Hoang Pham, 2006, Springer Science & Business Media
- Reliability and Maintenance Engineering, R C Mishra, New Age International, 2006
- Models of Preventive Maintenance (Study in Mathematics & Managerial Economics), Ilya B. Gertsbakh, North Holland, 1977

Material
Slides, Website, Jupyter Notebook

Resources

- Teaching Team (lectures en tutorials): Anne Barros, Zhiguo Zeng
- Outils informatiques: Python, Matlab

Learning outcomes covered on the course

- Design a maintenance strategy in a given application context
    - Make the appropriate modeling choice to assess the performance of a maintenance strategy
    - Know how to define and formalize relevant state variables
    - Know how to define and formalize a performance criterion
    - Know how to develop a model with the right level of abstraction from the description of scenarios or a set of transition/states
- Quantify performance from probabilistic or data-driven models
    - Know how to identify the right modeling framework based on stochastic processes
    - Know how to identify the right learning or machine learning algorithm according to a given data set
    - Know how to calculate probability laws or average quantities from an analytical formalism or Monte Carlo simulation
- Optimizing the performance of a maintenance strategy
    a. Know how to implement parametric optimization techniques for a given performance criterion
    b. Know how to formalize an optimization problem when the maintenance strategy is not fixed a priori

Description of the skills acquired at the end of the course

Validated skills:

- Design, model and recommend predictive maintenance strategies (C1.1 and C1.2)
- Being able to interact with business engineers and data scientists on this subject (C1.5 - milestone 2)
- Supervise the implementation of a predictive maintenance strategy from data collection to the practical implementation of maintenance activities (C1.5, milestone 2)
- The final case study is part of C1.3 (milestones 1B, 2B, 3B), C6.5 and C7.1

Validation mode

- Skills C1.1 (milestones 1 and 2) and C1.2 are validated during the TD sessions. Competency C1.1 is validated during the final case study for milestone 3.
- Competency C1.5 is validated during the final case study.

2EL2240 – Economics of decarbonised transport systems

Instructors : **Yannick PEREZ**
Department : **DÉPARTEMENT GÉNIE INDUSTRIEL ET OPÉRATIONS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **No**

Description

The course will examine three innovations that are set to profoundly transform the industry associated with personal mobility.The first two are primarily technological in nature, they are the autonomous vehicle and the electric vehicle - battery or hydrogen. The third is related to the penetration and generalization of new information and communication technologies and the IoT in mobility which allows the implementation of the principles of the sharing economy.
The motivation for studying the combination of these three innovations is to determine the conditions for moving from a model of individual ownership of mobility goods with considerable negative externalities in terms of pollution, congestion, accidentology to uses of services. of autonomous, electric and / or shared mobility which could provide solutions to the aforementioned problems.
This transformation of the means of mobility is therefore at the crossroads of engineering approaches (how to set up autonomous mobility, what uses of 5G for mobility, how to use artificial intelligence, how to include electric vehicles in electricity networks for smart recharging based on renewable energy, etc.), the industrial economist (what underlying economic models, what regulation of uses, what games of players in an industry undergoing profound reorganization) and analyzes of mobility needs and consumer behavior (what incentives for adopting behavior, acceptance of car-sharing, new behavior and micro-mobility, multimodal transfers, etc.). This course is an introduction to the M2 Economics of Energy, Environment and Transport, Economics of Transport and New Mobility course.

Quarter number

SG8

Prerequisites (in terms of CS courses)

nothing

Syllabus

Course 1: Introduction to energy transition and mobility.
Course 2: Electric Vehicle for Everything: Income Flow Framework
Course 3: Design pricing for EVs and renewable energy.
Course 4: Theories and applications of infrastructure deployments.
Course 5: Car Sharing Economics
Course 6: Car Sharing Economics an application in the Paris region
Course 7: Autonomous and shared electric vehicles: definitions, cost of technologies, shared mobility
Course 8: New technologies for urban and last-mile deliveries
Course 9: Mobility as a service
Course 10: New perspectives on urban mobility

Class components (lecture, labs, etc.)

During the 3 hour session, the first hour and a half will be led by a speaker (professor, researcher, town planner, economist, etc.) specializing in the topic. The tutorials will be held during the following hour and a half. In the tutorials, the students, in groups of 3, will make presentations on research articles made available to them by the speakers.

Grading

The course will be evaluated on the group work carried out during the tutorials for 60% of the final grade.
The 2-hour final exam will consist of 10 questions, for 40 % of the final grade

Course support, bibliography

Main Reference

Sperling, Daniel (2018) Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future. Island Press/Center for Resource Economics

Complements

· Icaro Silvestre Freitas Gomes, Yannick Perez, Emilia Suomalainen 2020 Coupling small batteries and PV generation: A review, Renewable and Sustainable Energy Reviews 126 (2020) 109835.

· Andrew Thompson and Yannick Perez 2020, Vehicle-to-Anything (V2X) Energy Services, Value Streams, and Regulatory Policy Implications, Energy Policy 137 (2020) 111136

· Quentin Hoarau & Yannick Perez, 2019, Network tariff design with distributed energy resources and electric vehicles, Energy Economics, Volume 83, September, Pages 26-39.

· Olfa Tlili Christine Mansilla David Frimat Yannick Perez, 2019 Hydrogen market penetration feasibility assessment: Mobility and natural gas markets in the US, Europe, China and Japan, International Journal of Hydrogen Energy Volume 44, Issue 31, 21 June 2019, Pages 16048-16068.

· Ramírez Díaz Alfredo, Marrero Gustavo, Ramos-Real Francisco, Perez Yannick, 2018 Willingness to pay for the electric vehicle and their attributes in Canary Islands, Renewable and Sustainable Energy Reviews Volume 98, December 2018, Pages 140-149.

· Ramírez Díaz Alfredo, Ramos-Real Francisco Javier, Perez Yannick, Barrera Santana Josue, 2018, Interconnecting isolated electrical systems. What is the best strategy for the Canary Islands? Energy Studies Review- Vol. 22 (2018) pp. 37–46.

· Hoarau Quentin and Perez Yannick, 2018, Interactions Between Electric Mobility And Photovoltaic Generation: A Review, Renewable and Sustainable Energy Reviews 94 (2018) 510–522.

· Rodríguez Brito Maria Gracia, Ramírez-Díaz Alfredo Jesús, Ramos-Real Francisco J., Perez Yannick, 2018, Psychosocial traits characterizing EV adopters' profiles: The case of Tenerife (Canary Islands), Sustainability 2018, 10, 2053.

· Codani Paul, Perez Yannick and Petit Marc 2018 Innovation et règles inefficaces : le cas des véhicules électriques, Revue de l'Energie n° 638, Mai-Juin

· Borne Olivier, Yannick Perez and Marc Petit 2018, Market integration or bids granularity to enhance flexibility provision by batteries of Electric Vehicles, Energy Policy, Volume 119, August 2018, Pages 140–148.

· Borne Olivier, Korte Klaas, Perez Yannick, Petit Marc and Purkus Alexandra 2018, Barriers to entry in Frequency-Regulation Services Markets: Review of the status quo and options for improvements, Renewable and Sustainable Energy Reviews. Volume 81, Part 1, January 2018, Pages 605–614.

· Codani Paul, Perez Yannick and Petit Marc 2016, Financial Shortfall for Electric Vehicles: economic impacts of Transmission System Operators market designs, Energy, Volume 113, pp 422-431.

· Eid Cherrelle, Codani Paul, Perez Yannick, Reneses Javier, Hakvoort Rudi, 2016, Managing electric flexibility from Distributed Energy Resources: A review of incentives for market design, Renewable and Sustainable Energy Reviews, Volume 64, pp 237–247.

Learning outcomes covered on the course

Analyze the technical, economic and social potential of electric, autonomous and shared mobility. Highlight the limits of the proposed solutions, the business models under development and the needs to be met to implement this new low-carbon mobility in smarter cities.

Description of the skills acquired at the end of the course

C1.1 Study a problem as a whole, the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human dimensions
C2.4 Create knowledge, in a scientific process
C3.6 Evaluate the efficiency, feasibility and robustness of the proposed solutions
C9.4 Demonstrate rigor and critical thinking in approaching problems from all angles, scientific, human and economic

2EL2250 – Public Sector Issues

Instructors : **Guillaume-Alexandre Collin, Éléonore MOUNOUD**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **No**

Description

The aim of this course is to make students aware of the challenges facing the public sector, to enable them to understand the changes taking place and to identify how, as CentraleSupélec engineers, they could contribute to these changes.

This includes
- acquiring a general understanding of how the public sector works and the role of each of the players,
- understanding the major transformation issues facing the public sector
- translating these challenges into several areas of public policy: how to contribute, within the public sector or in business

French public sector
Focus on the challenges of health and the ecological transition

Quarter number

SG6

Prerequisites (in terms of CS courses)

none

Syllabus

Introduction

General understanding of the public sector / fundamentals
- Role, organisation and operation of public players (specify)
- Hierarchy of norms and the making of law
- Public budget: public expenditure and revenue
- Public functions

Transformation of public action
- LOLF
- Design, management and evaluation of public policies
- State reform
- Public innovation

Digital transition of the public sector
- Digitisation of public services
- Data
- Digital inclusion

- Sovereignty

Public finance and procurement
- Public funding
- Public procurement

Social policy issues
- Health and social security
- Work and employment

The challenges of ecological transition and regional cohesion
- Mobility
- Resilience
- Access to public services
- Case study : MaaS

Regalian issues
- Police
- Armed forces
- Justice

Democratic issues ?

+ 2h exam (case study format)

Class components (lecture, labs, etc.)

Introduction (1h30) + 9 sessions of 3 hours each including a presentation, case studies presented by students and contributions from leading experts.

Grading

+ 2h exam (case study format)

2EL2410 – Signal compression and denoising

Instructors : **Gilles Chardon**
Department : **DÉPARTEMENT SIGNAL, INFORMATION, COMMUNICATION**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

This course is an introduction to signal and image representations, analysis, compression and denoising, fundamentals of modern signal processing for music and video storage, image enhancing in smartphones, processing and medical and astrophysical images, etc.

With the ever increasing quantity of collected and stored data, signal compression (images, sounds, videos...) remains a major challenge in data sciences, limiting the amount of necessary storage, and data transfers on telecommunication networks. Image restoration techniques (of which denoising is a particular example) are used on recent smartphones to mitigate the limitations of photographic sensors in resolution and sensibility.

A common point of the methods introduced in this course is their frugality in computations, energy, and data necessary for their development and use.

After recalling fundamentals of signal processing and harmonic analysis (filters, Fourier transform and series, random processes...), a first overview of signal denoising and compression will be given by Wiener filtering and LPC coding of speech.

The introduction of entropy coding will allow the design of lossless coders for images (PNG) and sounds (FLAC).

Lossy compression algorithms, with superior compression rates, will then be considered (JPEG, MP3, etc.).

Finally, wavelet orthogonal bases will be defined, with applications in image compression (JPEG2000), and non-linear image denoising.

Quarter number

SG6

Prerequisites (in terms of CS courses)

1SL1000 CIP
1SL1500 EDP
1CC4000 Signal Processing

Syllabus

1- Introduction

- Filtering, sampling
- Fourier series and transform
- Random processes

2- Wiener filtering and speech coding

- Linear denoising of random processes
- Speech models
- Linear prediction coefficients
- LPC coding

3 - Coding and quantization

- Source coding, entropy
- Lossless image compression (PNG)
- Universal coding and lossless sound compression (FLAC)
- Quantization

4 - Time-frequency representations

- Time-frequency orthogonal bases and frames (Short-time Fourier transform, DCT)
- JPEG image compression
- Audio masking and application to audio coding (MP3, Vorbis, etc.)

5 - Wavelet bases

- Wavelet orthogonal bases and fast wavelet transform
- Daubechies wavelets
- Application to image compression, JPEG2000
- Wavelet thresholding for image denoising

Class components (lecture, labs, etc.)

15h lectures
13h5 Tutorials/Labs
2h Final exam

Grading

Lab reports 30% Missed lab = 0 points for the lab Final exam 70%. Remedial exam : written exam 2h.

Course support, bibliography

A Wavelet Tour of Signal Processing, Stéphane Mallat, Academic Press

Resources

Personal computers, Python

Learning outcomes covered on the course

At the end of this course, the students will be able to
- Know the mathematical basis of non stationary signals representation
- Analyze signals using time-frequency representations
- Choose an appropriate representation for a given signal model
- Implement signal compression methods
- Recognize the limits of compression techniques
- Design, analyze and implement signal estimation methods

Description of the skills acquired at the end of the course

C1.2 Select, use and develop modelling scales, allowing for appropriate simplifying hypotheses to be formulated and applied towards tackling a problem.
C6.5 Operate all types of data, structured or unstructured, including big data.
C6.7 Understand information transmission.

2EL2420 – Digital image processing

Instructors : **Elisabeth LAHALLE, Charles Soussen**
Department : **DÉPARTEMENT SIGNAL, INFORMATION, COMMUNICATION**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

In many fields such as health, video surveillance, microscopy or remote sensing, simple or sophisticated image acquisition systems have been designed to produce digital images of all kinds: 2D images, 3D images, color images, videos, hyperspectral images. Image analysis includes the reconstruction of images from indirect measurements (e.g. in MRI and CT scan imaging), the reconstruction of 3D scenes in computer vision, image segmentation, image registration, and hyperspectral image analysis in remote sensing.

The objective of the course is twofold. On the one hand, fundamental concepts of image processing will be taught, ranging from elementary analyses to process grayscale and color images (thresholding, histograming, coding) to linear and non-linear filtering operations, carried out in the spatial domain and in the Fourier domain. On the other hand, advanced processing will be addressed to overcome the limits of conventional filtering approaches. They include image segmentation using geometric models to describe regions and contours, and the so-called variational approach, where image reconstruction is formulated as the optimization of a large-scale criterion. The variational approach is developed extensively and illustrated in the case of image denoising and image deconvolution.

Quarter number

SG8

Prerequisites (in terms of CS courses)

- Signal processing : convolution, Fourier transform
- Probability / statistics
- Optimization

Syllabus

Introduction :

Examples of image processing : shape recognition, image registration, image segmentation, image restoration and reconstruction.
Image acquisition systems, process of image formation, image formats.

Basic analysis:
- Histogram, contrast enhancement, thresholding of gray levels.
- Image sampling, image quantization and resizing
- Format of color images (RGB, HSV, etc.) and basic analyses.

Filtering :

Linear filtering :

- Notion of separability in the spatial domain.

- Smoothing and contrast filters : averaging and Gaussian filters, differential filters, Laplacian filter, Prewitt and Sobel filters, etc.
- Filtering in the frequency domain
Nonlinear filtering: median filter, order filter.

Contour detection and image segmentation : active contour and region growing approaches.

Variational approach (based on numerical optimization) **for inverse problems in imaging :**
- Optimization based approach for image restoration
- Tikhonov regularization
- Edge preserving regulariation
- Case of image denoising and deblurring

Class components (lecture, labs, etc.)

The course is organized in two parts to present:
- **Basic image processing:** 4 lectures , 3 TD
- **Advanced image analysis:** 5 lectures, long term project (11h)

The main concepts will be illustrated and some image processing algorithms will be implemented using a simulation and data analysis software such as Matlab.

Grading

The final grade will be composed of :
- a mid-term exam, 25 % of the final mark
- a project grade, 75 % of the final mark

Course support, bibliography

1. M. Nixon & A. Aguado, *Feature extraction & Image Processing*, éd. AP, 2010.
2. Jiri Jan, *Medical Image Processing, Reconstruction and Restoration*, éd. CRC Press, 2005

Resources

Additional teachers (a third teacher) for practical sessions if the number of students exceeds 50 (more than 2 groups of 25).

Learning outcomes covered on the course

1. Basic knowledge on systems of acquisition of numerical images (cameras, microscopes, …) and the process of image formation.

2. Ability to analyze a numerical image.

3. Ability to implement elementary numerical image algorithms : detection of pixels in an image by thresholding the gray levels, histogram computation, linear and nonlinear filtering, smoothing and contour detection.

4. Ability to implement advanced image deconvolution algorithms.

5. Learning advanced notions such as image segmentation based on geometrical models (contours and regions) and 3D image analysis.

Description of the skills acquired at the end of the course

The mid-term exam allows to participate in the validation of skills C1
The long term project allows to participate in the validation of skills C2, C6 and C8

2EL2510 – Architecture and design of digital systems

Instructors : **Anthony Kolar**
Department : **DÉPARTEMENT ÉLECTRONIQUE ET ÉLECTROMAGNÉTISME**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

In a top-down approach, students will learn how to specify and design dedicated digital processing systems, with the goal of integration into an FPGA or ASIC.
The microelectronic back-end aspect (placement routing) will be reserved for students wishing to specialize in the field and studied in third year honors.
The course will lead to the creation of an application, for example a small processing processor, and will thus make it possible to understand the various concepts used in this one.

At the end of this course, students will be able to:
• Define and design the architecture of a digital processing chain
• Describe a model of this treatment in VHDL.
• Design a simple processor and program it

Quarter number

SG6

Prerequisites (in terms of CS courses)

Few knowledge in Digital Electronic

Syllabus

Class 1: Architecture of processing units: data path and sequencer - part. 1
Class 2: Architecture of processing units: data path and sequencer - part. 2
Class 3: VHDL Description
Class 4: Time Analysis of Synchronous Systems
Class 5: GPUs: Architectures and Data Path Part. 1
Class 6: GPUs: Architectures and Data Path Part. 2
Class_TD 1: Algorithmic Logic Units share. 1
Class_TD 2: The Algorithmic Logical Units part. 2
Class_TD 3: Registers, memories and pipeline part. 1
Class_TD 4: Registers, memories and pipeline part. 2
Class_TD 5: The instruction game
Class_TD 6: The instruction decoding part. 1
Class_TD 7: The cache and its strategies
Class_TD 8: The instruction decoding part. 2

Class_TD 9: Executions and conditional jumps
Cours_TD 10: The compiler

Class components (lecture, labs, etc.)

1 - Definition of the notion of a Cours_PC:

1. This is a very strong interaction between a classical course and its almost immediate implementation, although here the approach is reversed: the exercises have as objectives to make realize where are the critical points without knowing the solution to there remedy. Once aware of the problem, the course brings the solution to students who are then much more sensitive. This approach is only possible under the condition that there is no clear cut between the course and the PC, hence the notion of Cours_TD.

ATTENTION: Absence from this part makes it almost impossible to fully understand the subject and therefore validate the course.

2 - Project to realize partially in homework and in team:

1. 6 project sessions (EL) of 1h30 in the presence of a supervisor
2. 21h homework (interspersed with previous project sessions).
3. 1 session of 3H with oral presentation then demonstration in front of the group of the result

The department will provide each student with an FPGA-type board (the same ones used for the first-year course) that they will keep until the end of their project.

Grading

- Examen - Processor Design
- Project Report and presentation

Ratio: 70% examen - 30% Projet

Resources

DE0 FPGA Board From Altera

Learning outcomes covered on the course

The course "Architecture of Digital Systems" will provide students with the concepts necessary to:

Define a processing architecture

Architecture of processing units: data path and sequencer
Description of each of the above functions in VHDL
Time analysis of synchronous systems

Design of a processor (Project type approach)

ALU, records and pipeline
Building a processor core
Instructional game
Instruction Decoding, Jumps and Pipeline

Data processing on graphic processor
GPU architecture: data path
Parallel programming language via CUDA type library

Description of the skills acquired at the end of the course

C1.1 Study a problem in its entirety, the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human dimensions.
C1.3: Solve the problem with a practice of approximation, simulation and experimentation.
C2.3 Identify and quickly acquire new knowledge and skills necessary in the relevant fields, whether technical, economic or other.
C2.5 Master the skills of one of the basic engineering professions (at the junior level).
C3.6: Evaluate the effectiveness, feasibility and robustness of the solutions proposed.
C6.3: Specify, design, produce and validate software.

2EL2520 – Electronics for biomedical and communication applications

Instructors : **Emilie Avignon-Meseldzija**
Department : **DÉPARTEMENT ÉLECTRONIQUE ET ÉLECTROMAGNÉTISME**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The objective of this course is to introduce the basics knowledge of electronics for biomedical applications, especially the acquisition and interface electronics. The approach proposed in this course is based on the study of practical cases. After several theoretical lectures, the student develops his skills in electronics through classical biomedical application like the circuits for ElectroCardioGramm, biomedical filtering (Gm-C techniques), pacemakers, timers... Every example seen allows to initiate the student to a particular concept in electronics. All along this course the students are invited to simulate their circuits on true biomedical data to verify their understanding.

Quarter number

SG8

Prerequisites (in terms of CS courses)

The first objective of this course is to introduce and sensitize the students to electronics through step-by-step real application cases. There is no need of a high theoretical level in electronics to follow this course. Nevertheless, it is recommended to master the very basics of electronic circuits to attend this course (Kirchhoff voltage and current laws, Ohms law). For students from CS, the elective "Electronic systems" is a good background. For students from abroad, any previous course with basics (Kirchhoff voltage and current laws, Ohms law, Opamp) is a good background.

Syllabus

Part 1: Introduction to basics of biomedical interface electronics (transistors, operational amplifiers, design of operational amplifiers), (12h00 HPE)
1.1 Introduction to the course, motivation
1.2 The transistor MOS
1.3 Basic circuits for interface based on MOS transistors
1.4 Opamp based circuit for biomedical applications: instrumentation amplifier
1.5 Method for designing operational amplifier at transistor level

Part 2: Study case of biomedical circuits, (10h30 HPE)
2.1 Biomedical filtering: Gm-C techniques
2.2 Biomedical embedded devices: example of pacemakers, timers.
2.3 Various biomedical circuits

Part 3: Practical works (6h00 HPE):
3.1 ElectroCardioGramm acquisition (Filters + Instrumentation amplifiers)
3.2 Design of Gm-C biomedical filter

Part 4: Training session (3h00 at home with office hours for questions)
A set of exercises and previous exams is provided with correction. The professor remains available for question in Office hour.

Class components (lecture, labs, etc.)

The course mixes theoretical approach with tutorials presenting classical practical cases commented by a teacher. This way the students get familiar with the reasoning methodology and will be able to reproduce these reasoning on other cases.

Grading

The presence during practical works is mandatory because the work provided during the sessions (calculation, searching solution) is evaluated. Each practical work count for 20% of the final grade. The written exam count for 60% of the final grade.
Competences C1 and C2 will be evaluated based on all activities. A mark greater than 10/20 will be required for the exam and a mark greater than 12/20 will be required for the project/practical work.

Course support, bibliography

Tony Cahn Carusone, David A. Johns, Kenneth W. Martin “Analog Integrated Circuit Design” Wiley

R. Jacob Baker « CMOS Circuit Design, Layout and Simulation” IEEE Series on Microelectronics Systems and Wiley

Resources

It is highly recommended to practice in order to master electronics. This is why this course mixes theoretical approach with tutorials presenting classical practical cases commented by a teacher. Most of the practical cases are illustrated by a LtSpice circuits available to the students, so they can be simulated simultaneously during the courses and increase the understanding of the phenomena.

Learning outcomes covered on the course

After this course, the students will be capable of:
- designing an electronic assembly to achieve an analog signal processing chain for biomedical or communication application
- analyzing an electronic assembly based on opamp, transistors and passive elements

Description of the skills acquired at the end of the course

Skills:
C1: Analyse, design and build complex systems with scientific, technological, human and economic components
C2: Develop in-depth skills in a scientific or sectoral field and a family of professions
C6: Be at ease and innovative in the digital world

2EL2530 – Integrated MEMS sensors

Instructors : **Jerome Juillard**
Department : **DÉPARTEMENT ÉLECTRONIQUE ET ÉLECTROMAGNÉTISME**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

In many application fields - automotive, medicine, aeronautics and defense, telecommunications or consumer electronics (smartphones, tablets) - the development or integration of miniaturized MEMS (Micro-Electro-Mechanical Systems) sensors is now a prerequisite for the deployment of connected applications. These devices are used as sensors (accelerometers, gyroscopes, pressure sensors, microphones, etc.), actuators (inkjet printers, optical displays) or for energy conversion. They have such advantages in terms of reliability, consumption, metrology, dimensions and cost that they have rapidly become essential (but invisible) elements of our daily lives since the 1990s and will play an increasing role in our future.

This course covers theoretical and practical aspects, from the point of view of modelling (multi-physical/multi-domain modelling, model order reduction), physics (mechanical, electrostatic, fluidic, fundamental metrological limits), technology (micro-manufacturing techniques, integration, packaging), and economics (profitability). It aims at providing a comprehensive overview of the field, which will be of interest to students with a taste for "beautiful physics" and for the design of complex systems, and/or those who wish to understand the large-scale industrialization of integrated devices.

Gap-year internships at major French and international MEMS companies are offered each year.

Quarter number

SG6

Prerequisites (in terms of CS courses)

No particular pre-requisite.

Syllabus

Lectures= 13.5 HPE
L 1 - Overview of MEMS (applications: sensors, actuators, transducers, main actors)
L 2-3 - MEMS Inertial Sensors, Mechanics and Modeling
L 4-5 - MEMS Transduction and Force Scaling
L 6-7 - Manufacturing, Integration and Packaging
L 8-9 - MEMS Industrialization

Labs = 6 HPE + 6 HEE
Homework - Pendular Accelerometer - modelling and simulation (first steps with Coventor) - 3HEE
Pen and paper lab - AM Resonant Magnetometer - 3 HPE
TD info - MEMS vibrating gyroscopes - 3HPE (separated modes) + 3HEE (degenerate modes)

Projects = 9 HPE + ??? HEE
Reverse engineering of a commercial 3-axis accelerometer

Study of a 2-axis resonant accelerometer
Optimisation of an FM resonant magnetometer
Modelling of MEMS acceleration switches
etc.

Class components (lecture, labs, etc.)

Lectures (13.5h), labs (6h), projects (9h)
Lectures and documents in English. Handout available in French.

Grading

Multiple choice test on lectures / labs (50%) Project report (50%).
Skills C1 and C2 assessed through multiple choice exam + project grade (excluding simulation part)
Skill C6 assessed through project grade (simulation part only)

Course support, bibliography

Practical MEMS, V. Kaajakari, Small Gear Publishing, 2009
Inertial MEMS, principles and practice, V. Kempe, Cambridge University Press, 2011
Micro Mechanical Transducers, Pressure sensors, Accelerometers and Gyroscopes, M.-H. Bao, Elsevier, 2000
Micromachined Transducers Sourcebook, G. T. A. Kovacs, McGraw-Hill, 1998

Resources

Coventor MEMS+ software (50 free licences granted by the company)

Learning outcomes covered on the course

Knowing the main types of MEMS sensors / actuators and their applications
Knowing the main fabrication, integration and packaging processes of MEMS devices
Knowing the main physical phenomena involved at the micro-scale (mechanics, transduction, dissipation, noise)
Understanding how MEMS inertial sensors (accelerometers, gyroscopes) work, from physics to electronics and control.
Being able to dimension such a system, and to simulate it using a professional design tool

Description of the skills acquired at the end of the course

C1/C2/C6

2EL2610 – Communications Theory

Instructors : **Sheng Yang**
Department : **DÉPARTEMENT SIGNAL, INFORMATION, COMMUNICATION**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

Communication is a fundamental need in all our societies. The ever-evolving communication networks and the emerging Internet of Things have become a decisive transforming factor in a large number of industrial sectors (e.g., telecommunications, multimedia, space exploration, surveillance, control, navigation, transport, health, agriculture, construction, environment). The amount of information exchanged has increased dramatically, and connectivity is becoming ubiquitous thanks to technological innovations and advanced processing. There are many new challenges: record-breaking high throughput and long-distance optical fiber channels, ultra-reliable low-latency mobile links for critical missions, reliable connection between billions of energy-efficient objects, exploding traffic of multimedia content delivery, outer space exploration ... The communication theory allows for a deep understanding of the fundamental limits of a communication system and how existing algorithms works, and more importantly, lays down the foundation for future engineers to solve the unknown use cases.

In this course, we focus on the general point-to-point communication system consisting of a source, a transmitter, a channel, a receiver, and a destination. The student will learn the mathematical tools and methods to model, analyze, design, and optimize the key components of a communication chain. First notions of information theory will allow the student to understand the minimum number of bits needed to describe a given source losslessly, as well as the maximum number of bits that the transmitter can communicate reliably with the receiver through a noisy channel for a given resource (e.g., time, bandwidth, power). This course also aims at providing a methodology to conceive a communication system with practical constraints due to technological or regulatory limitations (e.g., reliability, latency, energy efficiency, spectral efficiency, complexity, storage capacity, cost, consumption).

Quarter number

SG6

Prerequisites (in terms of CS courses)

- Model representations and analysis
- Signal processing
- Statistics and learning

Syllabus

1- Overview of communication systems
The communication chain : source, transmitter, channel, receiver, destination.
Layering and binary interfaces.

2- Digital representation of source and coding
Signal space point of view, equivalence between sequences and waveforms.
Sequence representation of a continuous-time source, sampling theorem. Quantization.

Different source models and their properties.
Information, entropy, source coding, construction of source codes.
Examples of practical compression algorithms : Lempel-Ziv, JPEG, MP3

3- Digital communication
Different communication channel models and their properties.
Additive white Gaussian noise channel. Digital modulation (PAM, QAM, PSK), Nyquist's criterion, passband modulation, baseband-passband equivalence.
Optimal detection rules, analysis of probability of error, signal to noise ratio. Practical implementation of transmitter/receiver.

4- Channel coding
Equivalence between continuous-time and discrete-time channels. Mutual information, Shannon's channel capacity.
Channel codes: linear block codes, convolutional codes, LDPC codes, polar codes.
Hard decoding, soft decoding, Viterbi algorithm. Performance analysis.

Lab sessions (with Python notebook):
Lab 1: Image compression with the Huffman algorithm
Lab2: Audio compression with subsampling and Fourier analysis
Lab3: Baseband modulation and communication
Lab4: Encoding and decoding of QR codes

Class components (lecture, labs, etc.)

Courses (16,5 H)
Exercise sessions (6H)
Lab sessions (6H)
Final written exam (2H)

Grading

Lab report (30%) Written exam (70%)

Course support, bibliography

1. R.G. Gallager. Principles of digital communication. Cambridge University Press; 2008.
2. A. Lapidoth. A foundation in digital communication. Cambridge University Press; 2017.
3. T.M. Cover, J.A. Thomas. Elements of information theory, Wiley, 2nd edition, 2005.

Resources

Lecturers:

- Sheng Yang teaches the lectures
- Sheng Yang, Richard Combes, and Antoine Berthet for the exercise sessions
- Sheng Yang and Richard Combes for the lab sessions

Group size for the exercise sessions: 20 students per group (max. 3 groups)
Software: Python

Learning outcomes covered on the course

At the end of the course, the student will learn the underlying mathematical principles of modern communication systems, essential both in further education and in the workplace in the long term. In particular, the student will be able to
- model, analyze, design, and optimize the key components of a point-to-point communication channel,
- construct simple source codes and channel codes for different purposes,
- build optimal decoder/detector for the receiver,
- manipulate the vector space of information sources and communication signals.

Description of the skills acquired at the end of the course

C6.7 Understand the transmission of information
C1.2 Use and develop suitable models, choose the right modeling scale and simplifying hypotheses to deal with the problem
C1.4 Specify, design, build, and validate all or part of a complex system
C2.1 Have deep knowledge of a field or discipline relating to the basic sciences or the engineering sciences

2EL2620 – Mobile communication networks and services

Instructors : **Mohamad Assaad**
Department : **DÉPARTEMENT SIGNAL, INFORMATION, COMMUNICATION**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

Communication networks have been widely developed and spread across the globe in less than half a century. Due to the emergence of new concepts and services (smart cities, industry 4.0, Internet of Things, etc.), networks are in great (r) evolution, especially with the development of 5G, to support the transformation of many so-called vertical sectors (telecommunications, transport, energy, health, agriculture, industry ...). Various types of services are thus transmitted over wireless networks nowadays.

The objective of this course is to understand the architectures of the current networks and to provide a prospective vision of their evolutions, as well as the cellular concept and the main radio techniques used to transmit data over wireless networks. This course presents also the theoretical foundations and tools used for the design, optimization, deployment and management of communication systems and networks. It addresses the dimensioning of a network and the determination of its coverage in practice, as well as the link between the capacity of a network and the quality of service to be offered to each user, using traffic engineering tools.

Quarter number

SG6

Prerequisites (in terms of CS courses)

none

Syllabus

- General introduction and architecture of mobile networks
    - Standard bodies. Spectrum allocation
    - Services (VoIP, multimedia content broadcast,...). New services (IoT, factory of the future, etc.)
    - Introduction to cellular networks (GSM, UMTS, LTE, 5G).
- Cellular Concept
    a. Cellular concept: Propagation models, radio access techniques
    b. Radio resource management: power control, interference management, Optimisation
    c. Network dimensioning, deployment, optimisation
- Traffic Engineering and Quality of Service
    - Traffic and Quality of Service. Quality of Experience. Quality of coverage and connectivity.
    - Traffic models and dimensioning: Erlang formula, queueing models, etc.
    - Mobility management: handover, routing, roaming

Class components (lecture, labs, etc.)

Organization of the lectures

-General Introduction: 1h30 (CM)
-Cellular Concept and Radio Access: 4h30 (CM) - 3h (TD) - 6h (TP)
-Traffic engineering and Quality of Service: 6h (CM) - 4h30 (TD) - 3h (TP)

TP 1: Performance of radio access techniques (3h)
TP 2: Capacity and coverage of wireless networks (3h)
TP 3: Traffic engineering and dimensioning of networks (3h)

Grading

Grading: - Final Exam: 2h (70% of the final mark)- TP: 30% of the final mark

Course support, bibliography

1- Harri Holma, Antti Toskala, LTE for UMTS: Evolution to LTE-Advanced 2nd Edition, John Wiley & Sons, 2011.

2- S. Stanczak, M. Wiczanowski and H. Boche, Fundamentals of Resource Allocation in Wireless Networks, Second edition, Springer 2009.
3- H. Holma and A. Toskala, WCDMA for UMTS, John Wiley & Sons, 2004.
4- R. Van Nee and R. Prasad, OFDM for Wireless Multimedia Communications, 2000.
5- T. Bonald, M. Feuillet, Network Performance Analysis, Wiley, 2011.
6- 3GPP Specifications.

Resources

Lecturers: Mohamad Assaad and Salah Eddine Elayoubi

Exercices sessions (TD): 25 students per classroom
software to use (TP): Matlab

Learning outcomes covered on the course

At the end of the course, the student will be able to:

1- know the architecture and different function of wireless networks
2- model a cellular network with its main functions
3- perform a cellular network planning
4- know the principles of network management and quality of service in wireless networks.
5- implement cellular network models and network management function using Matlab.

Description of the skills acquired at the end of the course

At the end of this course, the following skills will be validated
C1: Analyze, design and build complex systems with scientific, technological, human and economic components
C2 Develop in-depth skills in a scientific or sectoral field and a family of professions
C6 Be operational, responsible and innovative in the digital world

2EL2630 – Applications of statistical and quantum physics to information science

Instructors : **Zeno Toffano**
Department : **DÉPARTEMENT SIGNAL, INFORMATION, COMMUNICATION**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

This course is an opening to mathematical, informational and statistical theories and methods issued from quantum and statistical physics used in information science.

These methods are currently applied in many fields related to information processing, neural networks and deep learning, image processing, telecommunications, the semantic web, artificial intelligence, computational biology… but also more generally in the humanities and social sciences with, for example, applications in natural language processing and in finance.

The notions of entropy and information are central to this approach. For example, the study of disordered spin systems is applied to the processing of discrete information and statistical inference with important applications for example in telecommunications. More recently, operational techniques using quantum information have shown their advantage over conventional methods, the emblematic example being the quantum computer.

The purpose of the course, which is transdisciplinary in nature, is to establish connections between the training in mathematics and physics and advanced technological applications, such as digital communications, data processing, algorithmic learning and also quantum computation and information. It is intended for students wishing to familiarize themselves with research and engineering topics in top scientific and technological fields in a digital environment.

Quarter number

SG8

Prerequisites (in terms of CS courses)

analysis and probability theory, linear algebra, quantum and statistical physics and modeling.
Desired notions in information theory, machine learning, communications theory, algorithmic and complexity theory.

Syllabus

Classical information theory and applications
Measures and inequalities in IT - discrete case- continuous case. Maximum entropy principle.
Large deviations. Method of types. AEP entropy/entropy rates.
Entropy rate of stochastic processes. Markov chain. DPT. Second law of thermodynamics.
Data compression and transmission. Main coding theorems. Source and channel coding.

Quantum information theory
Quantum measurements, quantum entanglement and quantum entropym.

Quantum channels
Quantum communications and cryptography.
Quantum error correction.

Quantum computing and quantum simulation
Quantum gates.
Superdense coding and quantum teleportation.
Quantum algorithms I : Deutsch, Grover, Shor.
Quantum algorithms II : NISQ (noisy intermediate scale quantum) algorithms
Physical implementations.
Performance evaluation of quantum computing

Classical and quantum statistical physics applied to machine learning
Refreshers of classical statistical physics.
Ising models. Analogy coding/Ising.
Variational methods.
Boltzmann machines.
Landauer's principle and Maxwell's demon.
Quantum machine learning

Class components (lecture, labs, etc.)

28.5 HPE main and appliication courses

Grading

2 hour examination
personal work: oral presentation with slides of a recent scientific paper

Course support, bibliography

Mézard M., Montanari A., “Information, Physics, and Computation”, Cambridge, 2009.
Nielsen M., Chuang I., “Quantum Computation and Quantum Information”, Cambridge, 2001
Jaeger G., “Quantum Information: An Overview”, Ed. Springer 2007.
Djordjevic I.B., Quantum Information Processing, Quantum Computing, and Quantum Error Correction, An Engineering Approach, II Ed., Academic Press, 2021
Nishimori H., “Statistical Physics of Spin Glasses”, Clarendon 2001.

Resources

• Teaching team (names of lecturers) :
Antoine Olivier BERTHET and Zeno TOFFANO

Learning outcomes covered on the course

At the end of this course the student will be able to:
1) Understand in a multidisciplinary context the importance and impact of classical or quantum concepts of information and entropy
2) Using the mathematical tools of Statistical and Quantum Physics, interpret concrete cases, for example in the field of data sciences, telecommunications, artificial intelligence, computational biology or finance.
3) Propose mathematical models for innovative applications such as machine learning, neural networks, optimization, information networks, quantum computers, etc. using the means of information theory, statistical inference, optimization criteria, logic and quantum information learned during the course.
4) Implement mathematical models in the form of algorithms in different computer environments.

Description of the skills acquired at the end of the course

Learning outcomes 1 and 2 allow to reach the milestone 1 of the C1.1 skill, *ie* "Know how to make the influence of peremeters influent on the analysed system, the list of the elements with which it is in relation "and" Knowing how to identify important parameters with respect to the given problem".
Learning outcomes 3 and 4 enable to reach milestone 1 of skill C 1.2, that is, "Knowing how to use a model presented in the classroom in a relevant way." Making the choice of the simplifying hypotheses adapted to the problem".
Learning Outcome 4 also achieves milestone 2B of skill C 1.3, ie "Knowing the limitations of numerical simulations and what can be expected, namely, to criticize numerical simulation results. ".

2EL2720 – Disability commitment - Tutoring young people with disabilities

Instructors : **Lionel Husson**
Department : **DÉPARTEMENT DÉVELOPPEMENT PROFESSIONNEL ET MÉTIERS DE L'INGÉNIEUR**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **No**

Description

The "disability commitment" module combines theoretical and practical training on disability with field experience involving people with disabilities. The objective is to raise awareness and train students to understand what disability means, to adopt the right reflexes and to prepare them for diversity issues, while developing their adaptation, responsibility and managerial skills more generally. The field experience organized by the module leader is an educational and solidarity action : tutoring young people with disabilities (in secondary school or university) in order to help them overcome obstacles and promote their access to higher education and professional integration. Another field experience confronting disability and constituting an experiential learning situation can be proposed and subject to prior validation by the module leader
Teaching also accessible in 1A without this giving place to a replacement of the engineering sciences unit.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Tutors must be able to understand and express themselves in French.

Syllabus

1. Understanding disability and its consequences for students and on their studies, as well as disablity in the profesional world
2. How to define the appropriate context and adopt the right posture for engaging and conducting a tutoring session, and more globally an interaction with people with disability
3. Carry out, experience and adapt tutoring with one or more young people with disabilities or to lead a field action and commitment confronting the disability
4. Take a step back from the lived experience, formalize the acquisitions

Class components (lecture, labs, etc.)

1. The tutoring is declined in 2 ways

- Individual tutoring: in partnership with Sopra-Steria. A tutor accompanies a young person, in the form of learning support. The sessions take place according to the tutors' availability.
- Group tutoring: in partnership with Fédé 100% Handinamique. A group of tutors accompanies a group of young people, to help them clarify their training projects, gain self-confidence and express themselves in a group.

- Theoretical and practical training :
    - E-learning: SPOC "disabilities".
    - 1 session (3 hours) of sensibilisation on disability.
    - 1 session (3 hours) of training and role-playing workshop on conducting mentoring
    - 1 session (3 hours) of practical case studies on disability in companies
- Approximately 10-15 tutoring sessions (1h-1h30 each) to be carried out in the partner institutions during the school year according to a typically weekly rhythm adapted to the needs of the tutored students. If it is another engagement experience, it will include and equivalent volume
- Monthly follow-up and discussion (1h)
- 1 session (3 hours) for mid-term monitoring and sharing of experiences
- 1 session (3 hours) of assessment and presentation of the completed tutoring

Grading

Continuous monitoring (participation in training sessions; completion of tutoring sessions and debriefing) 50% + final evaluation ("learning journal" report and oral presentation) 50%
For the first learning outcome only simple knowledge or application is required, it will be assessed in the form of course questions, multiple choice questions in continuous assessment.
The next two learning outcomes require students to practise tutoring sessions and to step back from situations encountered. They will be assessed in two situations: in continuous assessment based on the course of the sessions (preparation and progress report and session report) and in final assessment by producing a report ("learning journal" illustrating the learning outcomes in relation to situations encountered and a reflective analysis) supplemented by an oral presentation.

Course support, bibliography

e-learning " disabilities ", tutor's booklet and various ressources on disability

Resources

- Teaching team (names of the teachers of the lectures): Lionel HUSSON and trainers from Sopra-Steria and Fédé 100% Handinamique

- TD size (default 35 students): 35
- Software tools and number of licenses required: no
- Public works rooms (department and capacity): no

Learning outcomes covered on the course

- Understand what disability means: types of disability, consequences for individuals and societal issues for the school and the professional world.
- Be comfortable interacting with people with disabilities

- Mobilize pedagogical, relational and organizational skills to structure and conduct an effective work activity with one or more people.
    - by working on the relationship to the other. Understanding the needs and expectations of one's interlocutors. Taking them into account in an evolutionary way. Encouraging interaction. Create a climate of trust
    - by working on oneself. Being helpful. Being convinced. Showing empathy. Managing emotions.

- Think and act as a responsible ethical professional with integrity, taking into account environmental, social and societal dimensions.
    - Acting inclusively when faced with diversity issues: identifying and understanding situations requiring integration actions and participating in an inclusive action in a specific process

Description of the skills acquired at the end of the course

This module contributes to the acquisition of the following competencies:

1. C9: Think and act as a responsible and ethical professional, taking into account environmental, social and societal dimensions.
    a. C9.4 : Act in an inclusive manner when faced with diversity issues: identify and understand situations requiring integration actions and participate in an inclusive action within a specific process
2. C7 : Know how to convince
    - C7.1 : on the substance : Structure your ideas and your argumentation, be synthetic (hypotheses, objectives, expected results, approach and value created)
    - C7.2 : on the relationship with others : Understand the needs and expectations of your interlocutors in an evolving way. Stimulate interactions, be pedagogical and create a climate of trust.
    - C7.3 : on oneself : Be at ease and show oneself convinced, show empathy and manage one's emotions
    - C7.4 : on communication techniques : master spoken, written and body language, and master basic communication techniques
3. C5: Evolve and act in an international, intercultural and diverse environment
        - C5.2 : Listen, make oneself understood and work with actors of various diversities, cultures, codes, training, disciplines, etc.

2EL2730 – Associative Elective

Instructors : **Ludovic-Alexandre VIDAL, Guillaume Mainbourg, Géraldine Carbonel**
Department : **DÉPARTEMENT DÉVELOPPEMENT PROFESSIONNEL ET MÉTIERS DE L'INGÉNIEUR**
Language of instruction :
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **No**

Description

The associative elective has four distinct paths:
EA1 - Set up a creativity approach in your association
EA2 - Structuring your association: creating values, processes and stakeholder management
EA3 - Set up a risk management approach in your associations
EA4 - IT project management
Other paths could eventually be created depending on the problems encountered by the associations.

Quarter number

SG6

Prerequisites (in terms of CS courses)

Belonging to a specific association / associative project.

Syllabus

Work on the mastery of these skills/knowledge through the establishment of concrete deliverables defined beforehand in the context of the path EAx, which should allow a good evaluation of the acquisition of skills.

Class components (lecture, labs, etc.)

Specific to each path EAx.

Grading

Establishment of precise deliverables regularly submitted.

Resources

3 courses of 1h plus delieverables to submit frequently over the course period.

Learning outcomes covered on the course

Specific to each path EAx.

Description of the skills acquired at the end of the course

Specific to each path EAx, but competencies C4, C6, C7, C8 and C9 could be validated with this course.

2EL5010 – Introduction to mobile applications engineering

Instructors : **Virginie Galtier**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Because of their ease of use and their ability to follow us everywhere, mobile devices (phones, tablets) have become first-class terminals and many companies have made the shift from "web-first" to "mobile-first" strategy.

This course focuses on the development phase of a mobile application, after the specification of its functionalities and before its possible publication on a store. Two main strategies will be presented: web applications, with limited functionalities usable on both Android and iOS, native applications, more powerful but requiring specific developments. A wide part of this course is dedicated to concrete work, on Android to illustrate the development of native mobile apps, and with Ionic and Angular (for example) to illustrate the development of reactive web site. Optionally, students will also learn about securing Android applications.

The knowledge and know-how acquired during this course may be useful in some curriculum-assigned projects, or in campus associations or enterprise activities.

Quarter number

SG6

Prerequisites (in terms of CS courses)

1CC1000 –Information Systems and Programming

Syllabus

Introduction

- Overview of mobile application development strategies
- Basics of Object Oriented Programming in Java

Android application development

1. Android system overview
2. Development tools
3. Design and implementation of applications based on Activities, Layouts and Intents

Introduction to web application development

- Basics of HTML5, JavaScript and CSS

- Design and implementation of a simple web application

Depending on progress: Introduction to Android applications security

- Presentation of common vulnerabilities
- Protection mechanisms

Class components (lecture, labs, etc.)

The structure "abs + lectures" is administrative because the course is actually mostly composed of "learning by doing" sessions led by teachers and industrial experts. The introduction to the security of android applications will take the form of an escape game.

Grading

The skills acquired by the student during the course will be evaluated on the basis of a final individual written test (1/2), and the development and presentation with a fellow student of a personal Android application with some imposed elements (1/2).

Re-take exam: 20-minute oral exam + new project with a predefined description, to be carried out individually

Course support, bibliography

- *Head First Android Development.* Dawn Griffiths, David Griffiths. O'Reilly. 2015
- *Building Progressive Web Apps: Bringing the Power of Native to the Browser.* Tal Ater. O'Reilly. 2017
- *HTML, CSS, and JavaScript All in One*. Julie C. Meloni. Pearson Education. 2014

Resources

Teaching staff: Virginie Galtier, Michel Ianotto, and guest speakers (InTech)
Tutorial class: 24 students
Lab sessions: computer rooms of Metz campus, 24 students /room
Software tools: free and open source software

Learning outcomes covered on the course

At the end of this course, students should be able to:

- understand and code object oriented programs in Java
- choose a development strategy according to objectives and resources
- build a simple web application
- develop a simple Android native app
- optionally, apply some best practices for securing Android applications

Description of the skills acquired at the end of the course

C1: Design: specify, implement and validate all or part of a complex system
C2: Develop in-depth skills in an engineering field and a family of professions n-depth skills in an engineering field and a family of professions
C6: Be operational, responsible, and innovative in the digital world

2EL5020 – Introduction to multi-tier application development and web services

Instructors : **Michel Ianotto**
Department : **CAMPUS DE METZ**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

More and more applications are built as a composition of services. The objective of this course is to present the underlying architectures and to introduce students to the development of solutions exploiting, creating and deploying services.

Enterprise applications access local or remote data, apply business logic to them, and then present or transmit the results. To ease their design, implementation and operation, they can be decomposed into layers and components. The Java Enterprise Edition (JEE) platform is designed to enable the development of these applications and their integration into existing information systems. The course will present the principles of the 3-tier architecture, with an implementation exploiting the main components of the JEE platform. The application will then be deployed in the cloud.

The application may require access to online data. Web pages are important data sources but they are designed for human interaction. A tedious process ("web scraping") needs be set up on a case-by-case basis so that a machine (a program) can recover the data exposed by web pages. Fortunately, many players such as Amazon or eBay for example offer another interface to access data, focused on resources or processes and not on graphical presentation. These "web services" simplify the data collection phase and allow their consumers to focus on their core business. This course will present how to discover a service, how to invoke it, and possibly how to build a composition of several services. It may also be relevant to open the developed application to partners (customers, suppliers ...). The course will present how to offer them such a service: how to design a service, develop and deploy it, describe it and make it discoverable.

Quarter number

SG8

Prerequisites (in terms of CS courses)

1CC1000 – Information Systems and Programming

Syllabus

Java programming basics

Introduction
- N-tier architectures
- Application servers
- The MVC model

Data persistence in Java

1. DBMS
2. The JPA specification
3. Object-relational mapping (ORM)

Business layer implementation

- Enterprise Java Beans containers(EJB)
- Presentation layer implementation
- JSPs and Servlets

Presentation of treatment-oriented services

- Architectural principles
- Introduction to XML
- SOAP protocol overview
- WSDL description language
- Practice: definition of a service contract, development of a server, publication of the interface to the client as a development kit

Presentation of resource-oriented services

- REST architectural style
- Introduction to JSON and OpenAPI
- Practice: development of a client application requesting online services, development, test and deployment of a service

Class components (lecture, labs, etc.)

The approximate distribution of "student presence hours" will be as follows: 24h of lectures and 9h of tutorial sessions in the computer room.
The structure "16 lectures + 6 labs" is administrative because the course is actually mostly composed of "learning by doing" sessions led by teachers.

Grading

Students' knowledge and skills will be evaluated regularly by short individual written tests during lessons and on the basis of a small project carried out in pairs and presented at the end of the course. Score weights: individual tests : 50%, project completion: 30%, presentation of the project: 20%. The catch-up exam will be in the form of oral exam with exercices partly done on computer. In case of a justified absence to one of the intermediary examinations, the grade of this latter is replaced by the grade of the final examination.

Course support, bibliography

- *Java EE : Développez des applications web en Java.* Thierry Richard. ENI. 2017
- *Web Services Foundations.* Athman Bouguettaya, Quan Z Sheng. Springer. 2014

Resources

Teaching staff: Virginie Galtier, Michel Ianotto, Patrick Mercier
Tutorial class: 24 students
Lab sessions: computer rooms of Metz campus, 24 students /room
Software tools: free and open source software

Learning outcomes covered on the course

At the end of this course, students should be able to:

- use an integrated development environment (IDE) to develop an application
- create an application in Java language implementing object-oriented programming concepts
- compose programs in Java using some annotations
- design and implement a business application with the JEE platform

- choose a service development strategy and implement it
- manipulate XML and JSON structured data
- develop a program requesting one or more services
- deploy a business application in the cloud

Description of the skills acquired at the end of the course

C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 : Develop in-depth skills in an engineering field and a family of professions
C6 : Be operational, responsible, and innovative in the digital world

2EL5030 – Programming efficiently in C++

Instructors : **Frederic Pennerath**
Department : **CAMPUS DE METZ**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **No**

Description

Knowing how to code an algorithm effectively in a given programming language requires a prior understanding of the associated calculation model and how the instructions in that language are translated into machine instructions. Too many students still approach programming in a superficial and risky way, lacking the basic knowledge necessary to write elegant and effective code.

The unique strength of the C++ language is to allow the production of compiled codes close to the optimal machine code while offering different high-level programming approaches such as strong typing, object programming, functional programming and meta-programming (automatic code generation at compilation). For this reason, C++ has become the essential language for developing optimized algorithms. Its only disadvantage is its richness, which has continued to grow in its most recent versions (C++11/14/17/20) and which makes it difficult to understand the language in its entirety without adequate training.

This course is intended for students, including beginners, who want to master the different aspects of C++ programming in order to be able to write code that combines performance and elegance. The course adopts a bottom-up approach starting from the mechanisms of elementary program execution and gradually moving towards the most advanced language functionalities.

The objective is to transmit to the students a real know-how of programming, on the one hand by illustrating the concepts through relevant examples of use, and on the other hand by devoting a significant part of the hourly volume to laboratory work.

Quarter number

SG8

Prerequisites (in terms of CS courses)

No specific requirements are expected, but a basic experience of programming.

Syllabus

- Total course length: 15h of lectures, 18h of labeworks and 3h of exam

Lectures (15h):

- Memory management and variable life cycle (1h30)
- Struct and smart pointers (1h30)
- Types (1h30)
- Functional programming: lambda functions, callable types, exceptions,... (1h30)
- Class and inheritance (1h30)

- Basic mechanisms of templates (1h30)
- Generic programming based on templates (1h30)
- Generic versus object-oriented programming (1h30)
- Standard library: content and concepts (1h30)
- System programming: threads and synchronisation mechanisms (1h30)

Labworks (18h):

- TP on memory manipulation (3h)
- TP on object-oriented programming and inheritance (3h)
- TP on functional programming (3h)
- TP on generic programming (3h + 1h30)
- TP on the standard library (1h30)
- TP on system programming (3h)

Practical exam (3h)

Class components (lecture, labs, etc.)

- Courses based on code examples
- Significant part (50%) devoted to practical programming work

Grading

The assessment will be based on a single examination scheduled at the end of the course.

This exam will last two hours and will consist of short programming exercises. Each student will work alone on his or her own computer without access to the Internet, but will be provided with all the necessary documentation to pass the exam (course materials, technical documentation).
The modalities of remedial examination will be identical to the ones of the initial examination.

Course support, bibliography

- Website provided by teachers
- Effective Modern C++, Scott Meyers, 2014
- Professional C++, Marc Gredoire, 2014
- A Tour of C++, Bjarne Stroustrup, 2013

Resources

- Two teachers: Hervé Frezza-Buet and Frédéric Pennerath
- No tutorials but only practical work on the machine
- One workstation per student
- One or two labwork groups of 15 students maximum each.
- The labwork will be carried out in the Linux environment and will be based exclusively on free software (g++, CMAKE, etc.).

Learning outcomes covered on the course

- To know how to write a program in C++ using different programming paradigms such as object programming, functional programming and generic programming.
- To know certain aspects of the C++ language that have a decisive influence on the performance of programs during their execution.
- To know the functionalities offered by the most recent specifications of the C++ language (C++11, C++14, C++17 and C++20).

- To know how to use a C++ compilation and debugging environment

Description of the skills acquired at the end of the course

- C2: Develop a deep competence in an engineering field and in a family of professions.
- C6: Be operational, responsible and innovative in the digital world.

2EL5040 – Big Data: data gathering, storage and analysis on clusters and Clouds

Instructors : **Stephane Vialle**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Decrease of sensor price make easier their usage in various environments (inside factories, cities, transports…) and generate many raw data flows. A similar increase can be observed with structured data available on the web or in private archives of companies. Some "Big Data" technologies have appeared and quickly evolved to manage and analyse these data sources.

This course presents the Big Data environments that have emerged to store and interrogate these new Big Data: in particular NoSQL BdD and distributed environments like Hadoop and Spark.These environments were born in the innovative web industries, and have brought new programming paradigms like Map-Reduce (implemented in several variants).

1. An important part of the course is devoted to the design of algorithms for filtering, enriching and analyzing data stored in Big Data environments. Most of these algorithms are based on the Map-Reduce programming paradigm and will be tested during labs. Performance metrics and criteria for scaling up distributed systems will also be presented and used in labs.

The last part of the course presents Machine Learning algorithms, used to process and analyze data sets, and which sometimes require the use of massive parallel computing on GPUs.

Quarter number

SG8

Prerequisites (in terms of CS courses)

- SG1 common course "*Systèmes d'Information et Programmation*" (1CC1000)
- ST2 common course "*Algorithmique & Complexité*" (1CC2000)
- ST4 common course "*Statistique et Apprentissage*" (1CC5000)

Syllabus

- **Introduction and terminology (1CM - 1h30):** Data Engineering vs Data Science, distributed hardware and software architectures, high performance data analysis, SMPD vs Map-Reduce parallelization.

- **Hadoop environment and technology (1CM - 1h30):** Distributed file system (HDFS), Hadoop Map-Reduce principle, resource manager version 1 with scale limit, and optimized version 2 (YARN).

- **Spark environment and technology (3CM - 4h30):** Spark performance-oriented architecture and mechanisms, simple Map-Reduce algorithm, Map-Reduce algorithm for graph analysis, Spark-SQL libraries and stream processing.
    - **Tutorial courses 1 & 2 (3h00)**
    - **Labs 1 & 2 (6h00)** on PC clusters

- **Metrics and scaling limits (1CM - 1h30): acceleration and efficiency metrics, scaling criteria.**

- **Data exploration and preparation (1CM - 1h30):** classic problems encountered with data, need for data exploration and preparation

- NoSQL data bases (2CM – 3h00): Emergence of NoSQL databases, NoSQL technologies, use of MongoDB
    - Lab 3 (3h00)

1. Introduction to Machine Learning (ML) technologies (3CM : 4h30): classification of ML algorithms, clustering algorithms, examples of ML libraries in Python
    a. Lab 4 (3h00)

    - **Written examination (1h30)**

Class components (lecture, labs, etc.)

Theoretical issues introduced during the different lectures will be experimented during some labs on Big Data clusters of CentraleSupelec *Data Center for Education.* These experimental plateforms will allow to request Spark and MongoDB environments, distributed on PC clusters and managing large volumes of data. During the last part of the course, some computing servers will allow to efficiently run Machine Learning libraries. Some performance measurements will complete the evaluation of the different solutions developped during the labs.

Composition of the course: lectures 18h00 (12 x 1h30), tutorials 3h00 (2 x 1h30), labs 12h00 (4 x 3h00) and a final written exam (1h30)

Possible schedule of the course:

- 3 courses, 1 tutorial course, 1 lab, 1 course, 1 tutorial course, 1 lab, 6 courses, 1 lab, 2 courses, 1lab
- Written exam (1h30)

Grading

Relative weights of the different examinations:

- 40%: lab reports. Any unjustified absence at labworks will result in a score of 0. A justified absence at a labwork will neutralize the score of this labwork and will increase the weight of the others.
- 60%: final written exam of 1h30, with documents.

Remedial examination: If a remedial exam is necessary, 100% of the score will depend on a written exam of 1h30, with same modalities than the initial written exam.

Course support, bibliography

Documents supplied to the students:

- Slides et notebook of the teachers.

Suggested books:

- Pirmin Lemberger, Marc Batty, Médéric Morel et Jean-Luc Raffaëlli. *Big Data et Machine Learning*. Dunod. 2015 (in french).
- Eric Biernat et Michel Lutz. Data Science : *Fondamentaux et études de cas*. Eyrolles. 2015 (in french).
- Bahaaldine Azarmi. Scalable Big Data Architecture. Apress. 2016.
- Kristina Chorodorw. MongoDB. The Definitive Guide. 2nd edition. O'Reilly. 2013.
- H. Karau, A. Konwinski, P. Wendell and M. Zaharia. Learning Spark. O'Reilly. 2015.
- Rudi Bruchez. Les bases de données NoSQL et le Big Data. 2ème édition. Eyrolles. 2016.

- Tom White. Hadoop. The definitive Guide. 3rd edition. O'Reilly. 2013.
- Donald Miner and Adam Shook. MapReduce Design Patterns. O'Reilly. 2013.
- Matthew Kirk. Thoughtful Machine Learning with Python. O'Reilly. 2017.

Resources

- 18h00 of lectures about Data Engineering including: the introduction to standard and distributed Big Data environments, and the design of fast and scalable solutions.
- 3h00 of tutorials about architecture sizing and Map-Reduce algorithmics.
- 12h00 of labs about experimentation of standard and Opensource Big Data software (Hadoop HDFS, Spark, MongoDB, Machine Learning libraries), on high performance computing servers and clusters (resources of the *Data Center for Education* of CentraleSupelec).

Learning outcomes covered on the course

When finishing the course, the students will be able:

- **[Learning Outcomes 1* (AA1*)]** Specify, design and present a complex and consistent system for large scale data analysis (contributing to core skills **C2 C6**):
  - to specify and to set the size of a Big Data hardware architecture
  - to choose a Big Data environment adapted to the use case (ex: Spark and some of its libraries, or some kind of NoSQL dtabases...)
  - to design a Map-Reduce based software architecture and algorithm, function of the available Map-Reduce variant (in order to clean, to prepare, to filter and to request large data)
  - to optimize a Map-Reduce based algorithm to improve its performances and scalability
  - to specify and to set the size of a Machine Learning hardware architecture (ex: CPU, CPU cluster, GPU, GPU cluster...)
  - present a convincing summary of the software and hardware architecture developed

- **[Learning Outcomes 2* (AA2*)]** Evaluate and present performances and strength of a Big Data architecture (contributing to core skills C2 C6):
  - to define a metric and a scaling benchmark adapted to the use case
  - to identify the bottlenecks of the hardware and software architectures (when increasing the data volume)
  - to identify the single points of failure of the global architecture
  - to identify the kind of incorrect data disturbing the analysis

Description of the skills acquired at the end of the course

- **C2:** Develop an in-depth skills in an engineering field and in a family of professions
- **C6:** Be operational, responsible, and innovative in the digital world
- **C7:** Know how to convince

2EL5050 – Estimation methods and introduction to the modern coding theory

Instructors : **Michel Barret**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **35,00**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

This course presents two key issues of decision theory: pure estimation and detection. More precisely, the following notions will be presented and implemented numerically: formalization of estimation and detection problems, influence of cost function, Bayesian / non-Bayesian point of view, prior information. The problems of estimating power spectral density and prediction, with finite and infinite past, of a second-order ergodic time series will be studied in detail. Finally, the four fundamental coding theorems for discrete memoryless systems will be presented with their proofs.

Quarter number

SG6

Prerequisites (in terms of CS courses)

- Probability 1A (CIP, 1SL1000),
- Signal processing ST4 (1CC4000)

It is advisable to have also followed:

1. Statistics, Machine learning and Data processing ST4 (1CC5000),
2. Digital environment, computer and programming SG1 (1CC1000).

Syllabus

- Fundamentals of estimation (6h of course)
  1.1 Introduction (goals of estimation, model, bayesian / non-bayesian point of view, examples)
  1.2 Bayesian estimation (Hilbert space, orthogonal projection theorem, mean square estimations with linear constraint)
  1.3 Elements of non-Bayesian estimation (Cramer-Rao inequality, maximum likelihood estimator)
- Estimation of a signal in an additive noise (3h of tutorials)
- Power spectral density estimation (non-parametric methods) (3h of tutorials)
- Detection (3h of course)
  4.1 Test of hypotheses (problem presentation, Bayesian theory, Neyman-Pearson strategy, ROC curves)
  4.2 Application to the detection of a signal in a noise (Karhunen-Loève decomposition, detection of a deterministic signal in a Gaussian noise)
- Detection (3h of tutorials)
- Linear statistical filtering (1h30 of course)
  6.1 Introduction and preliminaries
  6.2 Wiener filtering
- Wiener filtering with linear contraint (3h of tutorials)

- Prediction with infinite past (3h of courses)
  8.1 Case of a signal whose power spectral density is bounded and admits a strong factorization
  8.2 General case, Wold's decomposition
- Interpolation of a stationary signal (3h of tutorials)
- Prediction with finite past (1h30 of course)
- Primitives of the Information theory (3h of course)
  11.1 Introduction (discrete source of information, discrete channel, message)
  11.2 Four key coding issues (channel coding, channel approximation, distributed source coding, random extraction)
  11.3 Fundamental theorems (random coding, random binning)
- Exercises on the four key coding issues (2h of tutorials)

Class components (lecture, labs, etc.)

18h of courses + 17h of tutorials + homeworks

Grading

Evaluation of homeworks and some tutorials an evaluation in binomial (or trinomial) in the form Homework + Tutorials (spectral analysis) + report. This gives a grade1.

Two individual evaluations (short qcm)an individual evaluation (short qcm): grade2 and grade3.

The absence not excused at an individual evaluation gives the grade 0, the absence not excused in tutorials gives the standard penalties of the

Studies rule final grade = 1/2* grade1 + 1/6*(grade2 + 2*grade3).

Resit: an oral exam

Course support, bibliography

M. Barret, *Traitement Statistique du Signal*, ELLIPSES, 2009.
M Bloch et J. Barros, *Physical-Layer Security,* Cambridge University Press, 2011.

Resources

Some of the tutorials will be done with a computer (using Matlab or Python)

Learning outcomes covered on the course

At the end of this course, students will be able to deal with a wide range of concrete problems of estimation and detection, encountered in a scientific or industrial context. Starting from such a problem, they will be able:

- to model it by introducing a suitable cost function;
- to propose an adequate solution (adapted to the information a priori)
- to prove the optimality of the solution under certain conditions that they will be able to explain;
- to implement the method on data;
- to criticize the results.

In addition, at the end of the course, students should have acquired basic knowledge of the modern theory of coding for discrete memoryless systems (channel, source with side information to the decoder), where the above estimation and detection methods are applied.

Description of the skills acquired at the end of the course

Skills developed by the course

- C1: Analyze, design and build complex systems with scientific, technological, human and economic components
- C2: Develop an in-depth skills in an engineering field and in a family of professions

2EL5060 – Analysis and processing of audio data (speech and music)

Instructors : **Stephane Rossignol**
Department : **CAMPUS DE METZ**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

The aim of this course is to present the corpus of non-parametric and parametric spectral analysis methods, as part of the analysis of musical and speech sound signals.

Spectral analysis is one of the elements of signal processing chains; therefore, it is not just the visualization of spectra. The main objective is to decide and/or estimate. Some examples: What was the original score? Or what instruments are present in the orchestra? What is the fundamental frequency of this or that sound? What does this person say? Where is this person or this other one? Etc. The choice of this or that spectral analysis method is crucial, depending on the current problem.

The focus is put on the different concepts underlying each method, and the performance of these methods are compared. This last approach also highlights the concept of modeling (physical modeling/signal modeling/...), inherent in an efficient engineering approach.

Moreover, the various tools are studied in the context of the observation of the human being, who communicates with his fellow beings and his environment through his senses. Of these, sight and hearing are the best known, and only they allow a remote approach to the environment. Communication systems (human-to-human, human-to-machine or machine-to-human) are designed to acquire and reproduce these perceptions as faithfully as possible. It is therefore useful to know and be able to model in detail on the one hand the system of human perception, that is to say the receiver (the ear, here), but also the system of production of the signal concerned by the perception (human speech, music, various sounds), that is, the transmitter.

The sound platforms of the Metz campus (holophony room and anechoic room) are used for the practical aspects of this course.

This course has many areas of application: in-depth analyzes of time series; sound analysis for recognition and coding; phonetic coders for telephony; tools for the arts.

Quarter number

SG6

Prerequisites (in terms of CS courses)

Signal processing (1CC400).
Statistics and machine learning (1CC5000)
Programming experience (1CC1000)

Syllabus

- 1. Non-parametric spectral analysis methods (mainly based on the Fourier transform)
    - 1.1. Further information on these methods, already known
    - 1.2. Review of their limits
    - 1.3. Statistical means used to make the most of these methods
- 2. Parametric spectral analysis methods
    a. 2.1. Introduction to some of them
    b. 2.2. Contributions, compared to non-parametric methods
    c. 2.3. Cost of parametric methods
- 3. The sounds
    - 3.1. Models of perception (ear) and production (voice, mainly)
    - 3.2. Sound localization
    - 3.3. Virtualization of sound sources (holophony)

Class components (lecture, labs, etc.)

17.5h Lecture
9h Tutorials. (3 hours for each part of the lecture; sequencing Lecture/Tutorials: 6h L; 3h T; 6h L; 3h T; 6h L; 3h T)
8h Labs. A single topic.

Grading

Continuous monitoring (50%, 2/3 MCT at the beginning of the tutorials; individual score) and oral presentation at the very end of the labs (50%). Labs : grading by pair; differentiated in the event of an anomaly in a pair.

Course support, bibliography

Slides.

Resources

- Teacher : Stéphane Rossignol
- Room size for tutorials : 34
- Max room size for labs : 34
- Software : Matlab (34 licences)/Octave (Python)
- Rooms for labs : rooms on Metz campus

Learning outcomes covered on the course

- Design a complete signal processing chain.
- Compare the performances of the various tools at our disposal for the analysis of complicated time series, in order to choose the one which will be best suited for this or that signal to be analyzed.
- Program in an interpreted computer language (matlab/octave/python/...).
- Mastering the basic and advanced principles of analog signal processing and digital signal processing.
- Mastering the basic principles of sound perception (cognitive perception).

Description of the skills acquired at the end of the course

- C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components
- C2 : Develop in-depth skills in an engineering field and a family of professions
- C6 : Be operational, responsible, and innovative in the digital world

2EL5070 – Image processing

Instructors : **Jean-Luc Collette**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Image processing meets many areas of activity, such as medical imaging, satellite or robotics for localization in an environment. The preliminary step to image processing is its acquisition. The modeling of image sensors is therefore crucial to make the best use of the information that can be extracted. The images can also come from a reconstruction process such as that implemented in a scanner. The transmission and the compression of the images intervene in the quality of the results of their analyzes. We must understand its principles to take them into account in these analyzes. The different treatments that can be considered are then presented. Many applications will illustrate this course to have an overview on how to exploit the information in the image.

Quarter number

SG6

Prerequisites (in terms of CS courses)

- Signal Processing : 1CC4000
- Programmation and Information System : 1CC1000

Syllabus

1. Photometry, colorimetry, visual perception
1.1. Radiometric and photometric quantities
1.2. Perceptual models of the eye
1.3. Additive and subtractive synthesis
2. Color image sensors and rendering devices
2.1. Physical modeling
2.2. Geometric modeling
2.3. Calibration
2.4. Gamma correction
3. Other types of image
3.1. Multi and hyper spectral imaging
3.2. SAR imaging
3.3. LIDAR imaging
3.4. Overview of tomographic reconstruction techniques (scanner)
4. Coding and compression
4.1. Overview of orthogonal transformations
4.2. Overview of wavelet transformations
4.3. Still image coding
4.4. Image sequence coding
5.Improvement, image restoration
5.1. Improved contrast
5.2. Noise attenuation

5.3. Filtering from Wiener
6. Elements of mathematical morphology
6.1. Basic operators
6.2. Watershed
7. Geometric transformations and image registration
7.1. Nature of transformations
7.2. Metrics for registration
7.3. Specific optimization methods
8. Image segmentation and characterization of shapes
8.1. Region or edge approach
8.2. Extraction of features
8.3. Unsupervised classification

Class components (lecture, labs, etc.)

15h of lecture, 6h of tutorials and 14h of labs.
35 students for tutorial/labs groups

Grading

A written report will be requested on Laboratory Work (TP) and an oral presentation on this activity will also be organized (scheduled during labs). Any unjustified absence from a TP session will result in a zero mark. The final mark will be the equal average of the individual mark of the oral presentation and the mark of the laboratory work report.

The catch up exam will take place in the same way as the initial examination, with additional work requested in TP and an oral presentation of this work.

Course support, bibliography

"Digital Image Processing", William K. Pratt

Resources

Lectures will be given to present the main concepts.
Applications will be tested on computer during tutorial courses.

Learning outcomes covered on the course

• Knowing how to identify imperfections and limitations of operation of an image acquisition system.
• Knowing how to model and characterize this system in the optical domain.
• Knowing how to program or use basic processing algorithms (filtering, transformations) on digital images by mastering their complexity.
• Having an overview of how to use the information in the image.

Description of the skills acquired at the end of the course

C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 : Develop in-depth skills in an engineering field and a family of professions
C7 : Know how to convince

2EL5090 – Design of complex electronic systems: from component to heterogeneous system

Instructors : **Yves Houzelle**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

For a decade, French electronics has invested in high value-added areas and advanced sectors such as aeronautics, defense, medical, smart card payment, fiber optic telecommunications ..., discarding consumer products such as televisions and telephones.
Electronic systems cover a wide range of applications, ranging from analog electronics, with the amplifier as a basic function, to digital electronics, which implements the "smart" part of systems. In addition, the frequency range extends over a very broad spectrum ranging from low frequency applications such as audio processing to very high frequency applications such as radio communications.

The very different constraints related to this wide variety of themes impose different design tools that are adapted to each problem.
This course will provide students with basic concepts and knowledge of the tools used to design both analog and digital electronic systems.

Quarter number

SG6

Prerequisites (in terms of CS courses)

Control theory course of ST5. Having followed the 1st year elective course of Electronic Systems (1EL8000) can be a plus.

Syllabus

The course will present the components and methods of synthesis using the different tools (and understanding their limits) in order to give the future engineers the means to take part in the design of heterogeneous electronic systems.

Class components (lecture, labs, etc.)

Teaching will be given in the form of directed courses with presentations of concepts, application exercises and practical work.

Grading

A written report will be requested on Laboratory Work. The final written exam will count for 70% of the final grade. The Laboratory Work report will count for 30% of the final grade.The catch-up session will be in the form of an oral examination.
An unjustified absence in Laboratory Work will be penalized with a 0 for the session.

Course support, bibliography

- Documentations of components available on the internet.
- Modélisation des composants usuels pour la conception et l'analyse – Patrick Aldebert – 01134/01.
- Introduction à l’électronique analogique – Gilles Tourneur – 17189/01.
- Systèmes logiques et électronique associée – Volume 1 – Jacques Oksman, Jean-Philippe Szlowicz, Philippe Bénabès – 11121/01.

Resources

Teacher : Yves Houzelle.
LTspice software for analog simulation.
Quartus software for numerical simulation.
Education development board for digital part.

Learning outcomes covered on the course

- Know the concepts of analog and digital electronics : component modeling, polarization, linearization, large signal analysis, loopback and feedback, impedance matching, synchronous sequential logic, frequency behavior.
- Master the main tools of CAD and simulation.
- Be able to analyze electronic functions using the appropriate models.
- Know how to design and dimension electronic functions by taking into account the interfaces between components and with external interfaces.
- Know how to specify an electronic system, and write specifications.

Description of the skills acquired at the end of the course

1. C1 : Analyse, design, and build complex systems with scientific, technological, human, and economic components.
2. C2 : Develop in depth skills in an engineering field and a family of professions.

2EL5110 – Light to understand matter

Instructors : **Ninel Kokanyan**
Department : **CAMPUS DE METZ**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

There are many different characterization techniques that use *light*. Optical characterization techniques are generally non-destructive, fast and simple to implement, requiring very little sample preparation. These methods explore the change of intensity, energy, phase, direction or polarization of the light wave after interaction with the object under study. These techniques are now in great demand in the industrial world (quality control, surface characterization, atmospheric studies, food, biomedical and pharmaceutical analyzes, etc.).
The main purpose of this lecture is to address the most relevant examples of optical techniques with a focus on their applicability, usefulness and limitations. During the lecture will be presented different techniques that can be used in a complementary way and the obstacles that are frequently noticed during their use. Examples of practical and real applications will illustrate these points, offering suggestions on how it is possible to avoid obstacles as much as possible.

Quarter number

SG6

Prerequisites (in terms of CS courses)

1SL3000 - Lecture of quantum physics 1A

Syllabus

1. Introduction
2. Light scattering
3. UV-VIS-NIR spectrophotometry
4. Ellipsometry
5. Interferometry
6. Reflectometry
7. Photoluminescence
8. Infrared spectroscopy and Fourier transform infrared spectroscopy (FTIR)
9. Raman spectroscopy
10. Applications of optical techniques
11. Examples of applications in industry, biology, medicine, nanomaterials,...

Class components (lecture, labs, etc.)

20h of lectures, 6h of tutorials and 8h of practical work

Grading

Continuous assessment: QUIZ (25%), project (25%), final written exam (50%). In case of a justified absence to one of the intermediary examinations, the grade of this latter is replaced by the grade of the final examination.

Course support, bibliography

Mauro Sardela, *Practical Materials Characterization*, Springer-Verlag New York (2014)
Jin Zhong Zhang, *Optical Properties and Spectroscopy of Nanomaterials,* World Scientific (2009)
Peter Lasch and Janina Kneipp, *Biomedical Vibrational Spectroscopy,* A JOHN WHILEY & SONS, INC. (2007)

Resources

LMOPS Laboratory equipments
Teaching team : Ninel Kokanyan, Thierry Aubert

Learning outcomes covered on the course

1. To be aware of different optical techniques
2. To be aware of the operating principles of different spectroscopic components
3. Design and realize a device for optical measure
4. Be able to interpret obtained spectroscopic results
5. Identify the characterization technique suited for given material as well as for studied parameter

Description of the skills acquired at the end of the course

C1.2 : Develop and use appropriate models, choosing the correct modeling scale and simplifying assumptions when addressing problem
C2.1 : Thoroughly master a domain or discipline based in the fundamental sciences or the engineering sciences
C3.4 : Take decisions in an environment that may not be fully transparent, embracing the unexpected and calculating risk.

2EL5120 – Smart Photonics Systems

Instructors : **Delphine Wolfersberger**
Department : **CAMPUS DE METZ**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **No**

Description

In the context of new technologies, light is increasingly used as a support for calculating, transporting or storing information. The objective of this course is to present recent developments in "photonics", including lasers and their applications in different fields: ultra-fast optics, telecommunications, all optical information processing.

After a few notions of wave physics, the different types of laser sources will be discussed as well as the different components of a typical optical information transmission channel: from emitters (LEDs and laser diodes) to receivers (photodiodes) . A practical experiment on the transmission of sound will be set-up to validate the course. We will then discuss about different applications that we carry out in our laboratories using light: chaos in lasers, random numbers generation, holography for storing light, slow light... Some visits of labs will be organized to allow students to discover the world of research and innovation.

Quarter number

SG8

Prerequisites (in terms of CS courses)

none

Syllabus

Physical properties of lasers:
Laser basics principles, Fabry-Pérot cavity, threshold conditions, laser dynamics, modulation bandwidth.
Ultra-Fast Optics:
Generation of ultra-short pulses: femto-second lasers (Laser Ti: Sapphir), Optical Parametric Oscillator (OPO), Pulse measurement (auto-correlation).
Telecommunications basics
Network structure: access, transport, popular models – Traffic regulation: guided and free space propagation – Resources accessibility: TDMA, FDMA, CDMA – Different ways of communications: concurrency or complementarities.
Guided propagation, optical fibers
Guided wave theory: geometrical and wave approach of the optical fibers, attenuation and dispersion – Temporal Multiplexing – Wavelength Division Multiplexing: WDM, DWDM – Interconnects.
Components and optoelectronic interfaces
Light emitters: Electro luminescent diodes (DEL), Laser diodes, Emitting optical interface (modulation, noise, coupling, laser-fiber) – Photo detectors: PIN photodiodes, Avalanche photodiode, Reception optical interface.
Non-linear Optical Components
Non-linear propagation and solitons: non-linear Schrödinger equation, stability – Electro-optic effect – Optical parametric amplification.
Towards all optical network
Multiplexing – Amplification – Optical routing and commutation: micro-mirrors, liquid crystals, and spatial solitons.

Class components (lecture, labs, etc.)

30,5h lecture, 3h00 practical laboratory work

Grading

Oral evaluation (1h30) at the end of the course based on an oral presentation of 2-3 students : the mark will be individual.

Course support, bibliography

Les Composants Optoélectroniques, François Cerf, Hermes Science Publications, Paris 2000.
Fundamentals of photonics, E.A. Saleh, M.C. Teich (ISBN : 978-0-471-35832-9).

Resources

Educational team : Delphine Wolfersberger - Nicolas Marsal

Learning outcomes covered on the course

At the end of the course, the students will be able to:

- understand basics of lasers and their applications: holography, laser-based cryptography, optical buffering, optical memories ...
- understand the physical phenomena that are at the origin of lasers emission: threshold, resonance, ...
- become familiar with the ultra-fast optics: femto-second laser, optical parametric oscillator
- design and realize practically an optical communication for optical video/sound transmission
- understand notions of nonlinear optics used for the development of novel optoelectronic components.

Description of the skills acquired at the end of the course

C1 Analyze, design, and build complex systems with scientific, technological, human, and economic components

C2 Develop in depth skills in an engineering domain and a family of professions
C7 Know how to convince

2EL5130 – Chaos, Fractals and complexity

Instructors : **Damien Rontani**
Department : **CAMPUS DE METZ**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Neural networks, electronic or optical oscillators, or even chemical reaction are various examples of dynamical systems, where the state variable describing their spatiotemporal evolution evolve in a nonlinear fashion. From the intrinsic nonlinearity present in these systems stems rich dynamical behaviors, which allows for the observation of novel phenomena of interest for scientists and engineers. We can cite chaotic dynamics for example, explaining the impossibility to provide accurate long-term weather forecasting or collective phenomena, such as synchronisation, with multiple applications in neurosciences.

This lecture will provide to the student with the fundamental tools and framework of science of complexity. It will be illustrated by multiple example from recent research articles with application in the field of engineering. The student will use analytical and numerical techniques form the resolution of problems.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Basics in Linear Algebra and real analysis (level L2)

Classical Physics (Electricity, mechanics, Fluid dynamics...) (level L2)
Modeling (1CC3000 : Theory and analysis of linear dynamical systems, ordinary differential equations, and partial dérivative equations).

Syllabus

Context and Introduction (1.5h)
Discovery of Chaos theory: from H. Poincaré to E. Lorenz
B. Mandelbrot and discovery of Fractals
Examples of complex phenomena in physics, chemistry, and biology

General introduction to nonlinear systems and chaos theory (7.5h)
Introduction to the mathematical framework (Map, ODE, stability analysis)
Notions of attractors: fixed points, limit cycles, Torus, strange attractors
Bifurcations
Route to Chaos and strange attractors. Bifurcation diagrams.

Discrete-time systems (maps). Notions of Lyapunov Exponent. Analysis of complexity: dimension, entropy. Introduction to Cellular Automata.

The special case of nonlinear time-delay systems. Mathematical description with delay differential equations (DDE). Significance in Biology and Physics. Application of time-delay systems in photonics .

Introductions to Fractals (1.5h)
Introduction to the theory of fractals. Self-similarity and fractal dimension (Hausdorff). Cantor, Mandelbrot, and Julia sets.

Complex phenomena – Introduction to network physics (9h)
Definition of complex physical networks. Examples in biology (metabolism, genetic, neurosciences) and in engineering (transportation and power grids)
Collective and emergent phenomena. Notions of synchronization.
Examples of synchronization in Biology and Physics
Presentation of the Kuramoto Model.

Spreading phenomena on networks (epidemics compartmental modeling and statistical approaches on networks). Contacts networks.

Small classes and Labs (10.5h):
Numerical simulations of fractals (3h)
Analysis of complexity of a nonlinear map (3h)
Analysis and simulation of a network of phase oscillators and observation of synchronization (3h)
Numerical simulation and analysis of nonlinear dynamical system (3h)

Class components (lecture, labs, etc.)

Lectures with emphasized interactions with numerical and experimental demonstration. Priority given to physical interpretation and examples from current research. The presentation of mathematical tools is ilimted to essential notions necessary for the understanding of concepts seen in class.
Small class: (x2) will be organized for the assimilation of key notions
Labs: (x3) will be organized for experimenting with concepts seen in class and will focus on examples from current research topics.

Hourly volume:
Lectures: 18h
Small Class / Labs: 10.5h

Grading

Evaluation (Modalities and weight of each quiz/evaluation in the final grade) :

- Lab Reports are 100% of the total grade (they represent individual assignments). Unjustified absences during Lab session and/or missing Lab report: the grade of 0 is given to the corresponding Lab session.

Course support, bibliography

1. S. H. Strogatz, « Nonlinear Dynamics and Chaos : with Applications in Physics, Biology, Chemistry, and Engineering », Westview Press (2001), ISBN 978-0738204536
2. A. Pikovsky, M. Rosenblum, J. Kurths, « Synchronization: a Universal Concept in Nonlinear Sciences», Cambridge University Press, 2003, ISBN 978-0521533522
3. A.-L. Barabasi, "Network Science", Cambridge University Press, 2016, ISBN 978-1107076266

Resources

Teaching staff /faculty : Damien Rontani, Marc Sciamanna
Computing Ressources with Matlab and/or Python for laboratories and small classes

Learning outcomes covered on the course

To know the scientific context and multi-disciplinary aspects of nonlinear sciences and network theory.
To identify / recognize situations where is formalism can be applied to solve a problem.
To know and master a few basic methods for the analysis of nonlinear dynamical systems and nonlinear networks.

To perform numerical simulations of dynamical systems and dynamical networks

Description of the skills acquired at the end of the course

C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components

C2 : Develop in-depth skills in an engineering field and a family of professions

C6 : Be operational, responsive, and innovative in the digital world

2EL5140 – Modeling for Systems Engineering

Instructors : **Virginie Galtier**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

Complex systems involve many heterogeneous elements (mechanical, software, economic...). Systems engineering is an interdisciplinary approach allowing us to design, verify, and develop them in a controlled way. According to INCOSE (International Council on Systems Engineering), research shows effective use of Systems Engineering can save 10-20% of the project budget. It is not hard to know when Systems Engineering fails, because when something important goes wrong it usually makes the news fast. People get hurt, programs are delayed and over budget: from the problems encountered by the Hubble Space Telescope, to the crashes of Boeing’s 737 Max airplane, and the construction of the Channel Tunnel which came 80% over-budget. But when Systems Engineering goes right, no-one notices- which is just how it should be. This course focuses on modeling, on which rely systems engineering methodologies and tools.

Quarter number

SG6

Prerequisites (in terms of CS courses)

none

Syllabus

1. Introduction
    - definition(s) of a model
    - system lifecycle
    - objective and fundamentals of MBSE (Model-Based Systems Engineering)
    - introduction to SysML

Requirements Modeling
- stakeholder identification
- use case definition
- requirements diagram

Functional and Structural Modeling
- basis for structural decomposition, notions of interfaces
- block definition, activities and states diagrams
- allocation and traceability
- model animation

Decision Making
- matrix-based structural complexity management
- trade-off analysis

Additional topic
- an industrial point of view, topic may vary (example in 2022: the Modelica language, model exchange using the FMI standard)

Class components (lecture, labs, etc.)

The structure "6 labs + 16 lectures" is administrative because the elective is actually composed of sessions that include:

- a presentation of general concepts that can be reused by students in many contexts,
- an MCQ to check that the students have understood the key points,
- a guided practice exercise based on a common example.

Grading

Individual continuous assessment (50%) and presentation by group of two on a subject related to the course to be chosen among 10 propositions (50%, which would be made personal in case the contributions are too different from one student to the next)

Re-take exam: oral examination including a practical exercise on a computer

Course support, bibliography

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Guide to the SEBoK (*https://www.sebokwiki.org/wiki/Main_Page*)
INCOSE SE Vision 25 (*https://www.incose.org/docs/default-source/aboutse/se-vision-2025.pdf?sfvrsn=b69eb4c6_4*)
SysML Distilled, Lenny Delligatti, Addison-Wesley, 2014 (*https://app.ute.edu.ec/content/4915-114-4-1-6-19/SysML%20Distilled_%20A%20Brief%20Guide%20-%20Lenny%20Delligatti.pdf*)

Resources

Teaching staff: Virginie Galtier, and a guest speaker

Software: students are asked to install Cameo Systems Modeler on their PC according to the instructions and license provided in the first class; occasional use of other open-source and free tools

Note: Written material is mostly in English.

Learning outcomes covered on the course

At the end of this course, students:

- will be able to imagine a system modeling approach and will be familiar with a methodology (Magic Grid),
- will know the concepts of systems modeling,
- will be able to deploy a system model based on the different SysML diagrams,
- will be familiar with an industrial modeling tool (Cameo Systems Modeler),
- will be able to exploit some behavioral modeling techniques of a system in order to predict its behavior,
- will be able to integrate specific domain models using the FMI standard

Description of the skills acquired at the end of the course

- C1: Analyze, design, and build complex systems with scientific, technological, human, and economic components
- C2: Develop in-depth skills in an engineering field and a family of professions
- C4: Have a sense of value creation for his company and his customers

2EL5150 – Transitions and socio-economic symbiosis

Instructors : **Ninel Kokanyan**
Department : **CAMPUS DE METZ**
Language of instruction : **French**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category :
Advanced level :

2EL5160 – Social and solidarity economy, transitions and socio-economic models

Instructors : **Cynthia Colmellere**
Department : **CAMPUS DE METZ**
Language of instruction :
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category :
Advanced level :

Quarter number

SG8

2EL5170 – Innovation management tools at the service of responsible innovation

Instructors : **Cynthia Colmellere**
Department : **CAMPUS DE METZ**
Language of instruction :
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category :
Advanced level :

2EL6010 – Model based design of critical embedded control systems

Instructors : **Nabil Sadou**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Critical embedded control systems are present in various industrial fields (factory 4.0, Avionics, Railways...) but also in our daily live (home automation, automotive, medical...).

These systems, which are often critical, are subject to robustness, operational reliability and qualification constraints. This requires the use of specification methods that optimize the design process and formally guarantees all properties, particularly safety ones. The development of certified languages and tools reduces project certification costs by simplifying critical control applications design and automating verification, qualifiable/certified code generation, and documentation generation.

The objective of this course is to present the different processes of critical systems design.The different activities will illustrate the use of formal methods and models in the different stages from specification to solution design and code generation.

The courses also illustrate how the generated code is embedded on a hardware platform taking into account execution performance (time performance, sizing...). Integration, verification and validation processes will be also presented.

Quarter number

SG6

Prerequisites (in terms of CS courses)

Model Representations and Analysis

Syllabus

Introduction (critical systems, design, qualification, control systems, system development processes...)
Model-driven modeling and model transformation
Real time systems
System modeling and specification
Formal languages, synchronous languages,
Implementation of a control (Control of a Railways system) (see : https://youtu.be/BxieOtRYb9U)

Class components (lecture, labs, etc.)

lecture (12h), labs (21h), examen (1h)

Grading

written examination 1h (30%) project evaluation (70%)

Course support, bibliography

M. Klein, "A Practioners's Handbook for Real-Time Analysis : Guide to Rate Monoto-nic Analysis for Real-Time Systems", Kluwer Academic, Boston, 1993, ISBN 0-7923-9361-9.

Sanford Friedenthal , Alan Moore, Rick Steiner. « A Practical Guide to SysML, Second Edition: The Systems Modeling Language » (The MK/OMG Press), 2012

C. Bonnet et I. Demeure, "introduction aux systèmes temps réel", Hermes sciences. Paris 1999.

Richard Zurawski (Editor). Embedded Systems Handbook, Second Edition 2-Volume. June 25, 2009 by CRC Press Reference - 837 Pages - 225 B/W Illustrations ISBN 9781439807613

Resources

lecture, labs.

This course contains few lectures. The design of a railway network system project will be used to implemente the theorical elements defined in the differents lectures.

Learning outcomes covered on the course

By the end of this course students will be able :

1. to identify the real time aspects of an application, specify it and propose a design solution.
2. propose software structures and implementation.
3. to conduct performance analysis to demonstrate that the system can successively meet constraints and requiremennts.
4. to perform the different phases of the design cycle
5. to use a model based design approach.
6. design project management

Description of the skills acquired at the end of the course

- identify the real time aspects of an application, specify it and propose a design solution is part of C1.1Examine a problem in full breadth and depth, within and beyond its immediate parameters, thus understanding it as a whole. This whole weaves the scientific, economic
and social dimensions of the problem.
- propose software structures and implementation is part of C1.2Select, use and develop modelling scales, allowing for appropriate simplifying hypotheses to be formulated and applied towards tackling a problem.
- conduct performance analysis to demonstrate that the system can successively meet the system constraints is part of 3.6 Evaluate the efficiency, feasibility and strength of the solutions offered.
- perform the different phases of the design cycle is part of C1.4 Design, detail and corroborate a whole or part of a complex system and 3.6 Conceive of, design, implement and authenticate complex software.
- use a model based design approach C6.3 Conceive of, design, implement and authenticate complex software.
- design project management is part of C8.1 Work collaboratively in a team.

2EL6020 – Computer Architecture

Instructors : **Ruben Salvador Perea**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

This elective course is open to any interested student while it is also mandatory for the InfoSec track.

Microprocessors are omnipresent in today's society. However, their design, implementation and construction remain a challenge that have a major impact on the performance and overall security of computing systems.

The main objective of this course is to give students all necessary basic knowledge to understand how modern processors work. We will lay out the fundamental concepts and techniques in computer architecture, with a focus on the hardware/software interface and a bottom-up approach to understand how computers work and how they can actually be designed.

This course is largely inspired by Patterson and Hennessy's book "Computer Organization and Design, The Hardware/Software interface, RISC-V Edition, Morgan Kaufmann, 2018", and it will be used as the main book for the course. Both did pioneering work on computer architecture, specifically in "Reduced Instruction Set Computer" (RISC) architectures. David Patterson coined the term RISC, while John L. Hennessy was the inventor of the MIPS microprocessor. Both won the 2017 Turing Award for their work in RISC architectures.

Quarter number

SG6

Prerequisites (in terms of CS courses)

This course builds on fundamental concepts from:
- 1CC1000 – Information systems and programming
- 1EL8000 – Electronic Systems (particularly important is the "digital electronics" part)
Certain notions on algorithms & complexity fundamentals are also interesting.

Syllabus

Digital circuit design using a Hardware Description Language (HDL) (4.5h lectures + 6h labs)

- Combinational logic circuits design
- Sequential logic circuits design, Finite State Machines (FSM), análisis temporal
- Reconfigurable circuits: the Field-Programmable Gate Array (FPGA)
- HDL design flow for FPGAs (HDL description, simulation, synthesis)

Computer architecture and RISC-V (10.5h lectures + 12h labs)

1. The Von Neumann model of computer architectures
2. RISC/CISC architecture paradigms

3. RISC-V instruction set architecture (ISA), addressing modes
4. Processor components: datapath, register file, arithmetic logic unit (ALU), control unit, memory, peripherals
5. Interrupts and exceptions
6. Performance: pipeline, memory hierarchy and caches, branch prediction, out-of-order execution
7. Notions on processor architecture security

Tutorials and Labs

- VHDL design flow for FPGAs
- RISC-V assembly programming
- VHDL design of (a subpart of) a RISC-V processor

Class components (lecture, labs, etc.)

Lectures : 15h
Tutorials : 6h
Labs : 12h

Grading

Final exam (written or oral): 40%
Lab exam (project technical realization, demonstration and oral defense): 40%
Course assignments (exercises, readings ...): 20%

Course support, bibliography

- **Slides** provided to students

- **Main books for the course**: The are some copies of these books at the library and they are also available from the school ebook platform at: https://www-vlebooks-com.ezproxy.universite-paris-saclay.fr/
    - D. A. Paterson, J. L. Hennessy, Computer Organization and Design: The Hardware/Software Interface, RISC-V Edition, Morgan Kaufmann, 2018. [CA]
    - S. L. Harris, D. M. Harris, Digital Design and Computer Architecture (MIPS or ARM Edition), Morgan Kaufmann. [DDCA]

- **Other books**
    - W. J. Dally, R. C. Harting, T. M. Aamodt, Digital Design Using VHDL: A Systems Approach, First Edition, Cambridge University Press, 2016 [DD]
    - B. J. LaMeres, Introduction to Logic Circuits & Logic Design with VHDL, Second Edition, Springer, 2019 [DD]
    - M. M. Mano, C. R. Kime, T. Martin, Logic and Computer Design Fundamentals, Fifth edition, Pearson, 2015 [DDCA]
    - P. J. Ashenden, J. Lewis, The Designer's Guide to VHDL, Third Edition, Morgan Kaufmann, 2008 [DD]
- **Freely available PDFs**
    - B. Mealy, F. Tappero, Free Range VHDL : http://www.freerangefactory.org [DD]
    - P. J. Ashenden, The VHDL Cookbook : https://tams.informatik.uni-hamburg.de/vhdl/doc/cookbook/VHDL-Cookbook.pdf [DD]

Legend:
[CA] : Computer Architecture
[DD] : Digital Design
[DDCA] : Digital design and computer architecture

Resources

Teaching staff: Rubén Salvador, Guillaume Hie

- Maximum enrollment: 25
- Software: Xilinx Vivado
- Equipment-specific classrooms : Rennes Campus Level 5 lab rooms, 25 students

Learning outcomes covered on the course

At the completion of the course, students will be able to :

- explain the fundamental design principles of modern microprocessors architectures
- design some blocs of a simple microprocessor corresponding to the RISC-V instruction set architecture
- simulate and synthesize this microprocessor on an FPGA
- develop programs in assembly language using RISC-V instruction set

Description of the skills acquired at the end of the course

C1.4 - Design, detail and corroborate a whole or part of a complex system.

2EL6030 – Operating systems

Instructors : **Pierre Wilke**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

This teaching is part of the infosec course. The objective of this course is to give all knowledges required to realise a real kernel that is able to manage the process memory, the interruptions (and consequently the system calls), and is able to perform basic inputs-outputs.

Quarter number

SG8

Prerequisites (in terms of CS courses)

The prerequisites for this lecture are the following ones:
- Fluency in C language (e.g. by following the compilation course).
- Knowledge of RISC-V assembly language (e.g. by following the computer architecture course) would be a plus.

Syllabus

The course is organised as follows:
I Lesson 1:
- Operating system history
II Lesson 2 :
- Operating system startup
- Control registers
- Priviledge levels
- Interrupt management
- System calls
III Lesson 3 :
- Process scheduling
- Scheduling algorithms
- Context switching
IV Lesson 4 :
- Synchronization primitives in kernel and user spaces
- Concurrency problems
- Pseudo-concurrency and real concurrency
V Lesson 5 :
- Virtual memory management
- Segmentation vs pagination
- Memory protection
- Binary loading
- Memory allocation algorithms

Class components (lecture, labs, etc.)

Lectures: 15h
Labs: 18h

Grading

Final exam: oral exam
Mandatory evaluations: Reports for two labs, including the code produced to answer the questions, and the number of functional tests passed by the code.

NF=0.5 CF + 0.5 EO
Skill C2.1 is validated at milestone 2 by the validation of this course.
Skill C6.2 is validated at milestone 2 after having validated the practical exercises (having the average on the 2 practical exercises)
Skill C7.1 is validated at milestone 2 on the performance during the oral presentation.

Course support, bibliography

- Andrew Tanenbaum, " Systèmes d'exploitation ", 3eme Edition, Pearson.
- Russinovich, Mark, Solomon, David, Ionescu, Alex, "Windows Internals", 6eme edition, Microsoft Press.
- Daniel Bovet, Marco Cesati, "Understanding the Linux Kernel", 2nd Edition, O'Reilly.
- Love, Robert , "Linux Kernel Development: A thorough guide to the design and implementation of the Linux kernel (Developer's Library) ", Addison-Wesley.

Resources

Teachers: Frédéric Tronel and Pierre Wilke
Hardware: PC equipped with a Linux operating system.
Software: GCC cross-compilation chain for RISC-V, qemu-riscv64 and docker (we provide an installation guide for these tools during the first lecture).

Learning outcomes covered on the course

Understand the concepts involved in the design of an operating system.
Understand the impact of services offered by an operating system on the performance and security of applications.

Description of the skills acquired at the end of the course

C2.1 Have studied in depth a field or discipline relating to the basic sciences or engineering sciences.
C6.2 Design software
C7.1 Structure your ideas and arguments, be concise (hypotheses, objectives, expected results, approach and value created).

2EL6040 – System programming under linux and windows

Instructors : **Pierre-François Gimenez**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

This elective is part of the InfoSec track, but is nonetheless open to any 2nd year student willing to attend it.
The C language is still one of the most widely used languages to program low-level software applications in operating systems or application layers closeby. In particular, it is widely used for background services in GNU/Linux and Microsoft Windows systems (web servers, database servers, e-mail servers, file servers, and so on). Although designed a long time ago (in the 1970s) this state of things is due to the unchallenged performance of C programs, thanks to the continuous progress of available compiler toolchains. The drawbacks of writing in such a concrete language are therefore (partially) balanced by near-optimal performance, at the cost of a substantial effort for program design.
This course is therefore oriented towards students willing to strengthen their programming skills through experience with the C language, by writing applications close to the OS using standard UNIX interfaces (POSIX standard, I/O management, inter-process communication, multiprocess / multithread programming, system signal handling, debugging and application design and implementation) and their Microsoft Windows cousins with the Win32/Win64 APIs.
This course will also be the opportunity to realise the intrinsic difficulties of programming in C (especially the explicit memory management and the consequences of arguable design decisions in the implementations of arrays and strings) and the safety and security problems they incur.
We will use this experience to introduce a new programming language (Rust), which allows to guarantee both more security and safety (by language design, especially thanks to its rich type system) and achieves high performance just like C programs. To the best of our knowledge, this is the first language in programming languages history that reconciles security/safety with performance (previous attempts always sacrificed either security or performance). The Rust language is already currently used by Mozilla developers for the web browser Firefox.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Systèmes d'information et programmation, Algorithmique & Complexité, réalisation préalable d’un projet de développement logiciel (1A)

Syllabus

Part 1 : The C language
Part 2 : The Rust language
Part 3 : System APIs in Unix and Windows, POSIX standard

Class components (lecture, labs, etc.)

50% courses, 50% practical work, mini-project

Grading

Final exam (oral presentation of the project) : 33%
Code exam : 33%
Evaluated lab session: 33%

Course support, bibliography

- Le langage C - 2e édition - Norme ANSI (August 20, 2014) , Brian W. Kernighan and Dennis M. Ritchie.
- The Rust Programming Language, May 2018, Steve Klabnik and Carol Nichols.
- Programming Rust (August 2016), Jim Blandy.
- La norme POSIX.
- Windows System Programming, (4th Edition) (Addison-Wesley Microsoft Technology) by Johnson M. Hart (2015-10-01).

Resources

A Linux and Windows environment

Learning outcomes covered on the course

Create efficient C and Rust programs on the Linux and Windows platforms.
Select and make use of the OS kernel functions and their APIs.

Description of the skills acquired at the end of the course

C2 Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.
C6 Conceive of, design, implement and authenticate complex software.
C7 Convince

2EL6050 – Modelica and bond graph: multi-domain modeling, analysis and simulation

Instructors : **Pierre Haessig**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

This course offers to expand your know-how, as well as your theoretical understanding, of the modeling, analysis and simulation of complex multiphysical systems (e.g.: simulation of drones, building thermal performance, bioreactors…).
Context: technical systems are usually made by **assembling components** (ex. in a car: engine, starter, brakes…) which behavioral models come from **different technical fields** (electrical, mechanical, thermal…). As a result, these components are often mastered by **different people**. The engineering of complex systems therefore raises difficulties in **exchanging and building up models**. This elective aims to learn two commonly used modeling tools to meet these needs: Modelica and bond graphs.
The bond graph is a *graphical description* of energy links between the components of a system. This representation is based on analogies between physical domains (e.g. mechanical inertia ~ electrical inductance). With bond graph modeling, it becomes possible to perform structural analyses of the modeled system, in particular through the core notion of causality. These analyses reveal the *physical functioning* and the *energy exchanges* of the system.
Modelica is a non-proprietary language* used to address the following needs:

- Model systems spanning several physical domains
- Easily build structured models using reusable components
- Collaborate effectively and build up models within a team

*unlike Simulink/Simscape for example
Modelica allows you to easily (e.g. graphically) describe and then simulate the dynamics of complex systems (a few thousand variables). It is thus becoming increasingly popular in industry (building, transportation, electrical networks, etc.).
Thanks to the open source nature of the software being used (OpenModelica), you will be able to freely reuse the know-how of this course in different settings. Beyond Modelica, the acquired skills on model structure and collaboration will be applicable to many other environments.

Quarter number

SG6

Prerequisites (in terms of CS courses)

None

Syllabus

Course schedule:
Bond graph (5 h + 2 h personal work)

1. Principles of the bond graph formalism, analogies between domains
    a. procedure for assigning causality

2. Analysis of structural properties
3. Extraction of the state-space equations

Modelica (14 h + 6 h personal work)

- Introduction to Modelica: brief history, use in industry, principles
- Getting started with Modelica
    - First practical examples: ODE, electrical circuit, mechanics.
    - Analogies between variables: flow and potential
    - Hybrid systems, discontinuity, events (example of a diode rectifier)
- Structuring of models
    - Inheritance and composition
    - Packages
    - Creation of a customized physical component

Versioning (2 h + 1 h personal work, as required)

Depending on students' needs, there will be exercises to help people get started with Git (versioning software) and GitLab (collaborative development platform).

Modeling project (9 h + 18 h personal work)

(*"M³ project": Multiphysics Modeling with Modelica*) in groups of 3–4.

- Examples of project subjects: tidal power plant, drone, fuse, electromagnetic switch. *New in 2020-2021: modeling de dynamics of the COVID-19 disease!*

Final evaluation (2 h, see §Evaluation methods)

Class components (lecture, labs, etc.)

For bond graph, teaching is done through interleaved lectures and exercises.

For Modelica, teaching is done through practical computer-based exercises with concise lectures to introduce key concepts.

In order to enable a practical mastery of these two tools, the focus is on practice through small exercises in the classroom, small exercises in self-study between classes and finally with the final project.

Grading

The evaluation of the elective is based on two activities:

- **Final exam on theoretical aspects**, without documents, on bond graph and Modelica fundamentals (50% of the final grade)
- **Modeling project** (50% of the final grade)
    - A sheet detailing the project's objectives is given at the start of the project. In relation to these objectives, the evaluation criteria are listed in detail.
    - The project grade can be individualized within a group

Moreover, this elective takes place in the form of applied courses where most of the learning happens in the classroom. Participation in class is therefore essential to acquire the knowledge and skills of this elective. The **participation** and the respect of the deadlines thus count for a part of the final grade.

Course support, bibliography

Material of the Modelica course: http://éole.net/courses/modelica/

- including an extended list of references: http://éole.net/courses/modelica/90-references.html

Material of the Bond graph course: slide deck of the teacher *"Bond Graphs - A graphical language for the analysis of multiphysical systems"*. https://cel.archives-ouvertes.fr/hal-03602684

Michael M. Tiller *"Modelica by Example"*, online book, first published in 2014 an continuously updated since. URL: mbe.modelica.university.

Geneviève Dauphin-Tanguy et al. *"Les bond graphs"*, livre Hermès, 2000.

Resources

Teacher : Pierre Haessig

Computer sessions using the free software OpenModelica

Please note that installing the software under macOS is difficult. It may be necessary to work with a Linux virtual machine. As an alternative, Parallels Desktop (paid) was successfully tested in 2021-2022.

Learning outcomes covered on the course

For bond graph, the course is about learning the concepts of this representation to be able, on simple examples, to:

- model the system by a bond graph
    - including the application of the causality assignment procedure
- analyze the structural properties of the system
- extract the state-space equations

For Modelica, the course objectives are:

- use the Modelica language and the OpenModelica development environment to model and simulate dynamic systems
- know how to reuse standard Modelica models
- structure a complex model into reusable components
- work in a team on a common complex model, with a versioning system (git)

Description of the skills acquired at the end of the course

The skills described above make it possible to validate the following CentraleSupélec engineering skills:

- **C1**: **Analyze, design, and build complex systems** with scientific, technological, human, and economic components. In particular:
    - C1.2: **Modeling**: using and developing the appropriate models, choosing the correct modeling scale and the relevant simplifying assumptions
    - C1.4: **Design**: specify, implement and validate all or part of a complex system (in this course, the “complex system” to be designed is in fact the *Modelica model* of a complex system)

- **C6**: Be operational, responsible, and innovative in the **digital world**. In particular:

    a. C6.1: Solve a problem numerically (in particular the simulation of dynamical systems)
    b. C6.2: **Design software** (the Modelica model being seen as software)

2EL6060 – Serious Game

Instructors : **Gwendal Fouché**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

What if you save the world from your console?

The game, and especially the video game, is a fascinating medium. You have certainly experienced a maximum concentration, facing a screen or a board, hours that we no longer feel, challenges and limits that are crossed and exceeded. The game does not announce its ideas, it makes them live. The game does not explain, it implies.

Today, this strength of the game shows us that it is possible to go beyond mere entertainment: more and more, it allows to transmit knowledge, know-how, ecological or social awareness, ... In short, the game becomes seriously useful, from industry to classrooms.

In this elective, you will discover how the serious game has transformed the transmission of ideas in many areas, from learning to read to car repair, through education to gestures of care. These examples will allow you to become a designer of your own serious game, because your ideas also deserve to be playable.

Highlights

Discover and analyze several use cases and their effectiveness
Introduce one of the major themes of the serious game by making a YouTube popularization video
Build and develop as a group project your own serious game using a video game development platform such as *Unity*

Quarter number

SG8

Prerequisites (in terms of CS courses)

Computer science :

- Algorithms
- Programming language (basis)

Syllabus

Background (10%)

a. Introduction to the elective and major issues around the serious game.
b. Discoveries of industrial problems and specific cases throughout the elective.
c. DragonBox: How do 5-year-olds learn algebra in 50 minutes?

YouTube popularization video (25%)

- Subject choice among several proposed themes (game design vs gameplay, role of the score, interaction loop, ...)
- Creation of a YouTube video explaining the issues of the chosen theme (1 production per student).
- Share and watch videos on the Youtube channel dedicated to the elective.

Realization of a proof of concept of serious game (65%)

- In groups of 3 to 5 people.
- Accompanied by a professional in the video game industry.
- On a subject of your choice.
- The design, as well as the supervision will be done in two distinct but complementary sets:
    - the serious aspect, the useful objective to reach, the message or the knowledge to be transmitted;
    - the game aspect, the mechanics of the game implemented so that the interaction with the player works.
- Test your creation with your classmates and your entourage, and make it evolve in iterative mode!

Class components (lecture, labs, etc.)

- Presence course: 10% (6 HEE)
- PW and evaluation: 40% (24 HEE)
- Project and YouTube video : 50% (30 HEE)

Grading

Youtube video on a theoretical aspect of the serious game: 1/4 of the note and C3

Example analysis of a serious game : 1/4 of the note and C2
Pitch and Defense of the project of realization of a serious game: 1/2 of the note and C2, C3, C6, C8

Course support, bibliography

Introduction au Serious Game, de Julian Alvarez et Damien Djaouti
Concevoir un serious game pour un dispositif de formation, de Béatrice Lhuillier
Les serious games. Une révolution, de Yasmine Kasbi
La Gamification: Ou l'art d'utiliser les mécaniques du jeu dans votre business, de Clément Muletier et Guilhem Bertholet
Serious Game : Révolution pédagogique, de Valérie Lavergne Boudier et Yves Dambach

Resources

Teaching team:
- Catherine SOLADIE
- Externals

Size of PW : <= 30

Software tools and number of licenses needed:
- Unity (free for students): https://unity3d.com/en/unity

PW rooms:
- 251 and 252, Rennes Campus (up to 30 students in each room / 15 posts per room)

Learning outcomes covered on the course

At the end of this lesson, you will be able to:

- Define the main concepts related to serious games (C2.1)
- Argue the practices implemented in existing serious games (C2.3)
- Implement a video game (C6.2)
- Combine your software development skills with new skills (such as pedagogy or medicine) in a multidisciplinary approach (C2.2)
- Imagine and design a serious game (C3.3)
- Be proactive and get involved in the creation of a YouTube video and a POC (C3.3)

- Take into account the game play and the UX in the creation of a serious game (C4.2)
- Use the expertise and personal knowledge of at least one member of the group (eg music, art, science, ecology) to design a serious game (C8.1)

Description of the skills acquired at the end of the course

- C2 Jalon 2
    - C2.2 **Importer** : Réutiliser concrètement des connaissances issues d'un autre domaine ou discipline dans un problème donné
- C6 Jalon 2
    1. C6.2 **Concevoir un logiciel** : Par le biais d'une réalisation pratique, modéliser un logiciel complexe
- C3 Jalon 2
    - C3.3 **Innover** : Etablir des POC ou équivalent
- C8 Jalon 2
    - C8.1 **Travailler en équipe** : Associer chaque membre de l'équipe en fonction de ses forces

2EL6090 – Artificial Intelligence and Deep Learning

Instructors : **Catherine Soladie**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

DNA or line of code?

Homo Sapiens is cut to walk on two feet, yet he must learn a year before getting up. Underwater creatures can move in total darkness, and their species have evolved over millions of years to achieve this result. Adaptation to a milieu, to a problem, or intelligence, are not static notions but the result of a constant effort: learning.

Thus, the emergence of technological systems capable of prediction, of expertise, quickly raises the question of learning. How can a program acquire, assimilate, organize knowledge? On this point, taking inspiration from the living is a rather fruitful starting point. How to mimic the behavior of our neurons? That of evolution and natural selection? What results to expect?

In this elective, you will discover the principal methods of Artificial Intelligence and how they work. You will be able to take in hand the most recent algorithm on concrete cases, and you will have the opportunity to push the study on a subject of your choice. It's up to you to learn how to learn!

Highlights

Artificial life: cellular automata, neural networks, genetic algorithms
Deep Learning: Convolution networks and Transformers, Temporal processing of data (RNN, LSTM), Generative models (like VAE or GAN)

Quarter number

SG6

Prerequisites (in terms of CS courses)

Statistics and learning.

Syllabus

Background (5%)

- Introduction to the subject
- Historical context.
- Link with the subjects of the program.

Artificial life (15%)

1. Alternation theory / practice in the form of applied course

- Artificial Life
    - Cellular automata and emergence concept
    - Genetic algorithms
    - Multi-agent systems
    - Reinforcement Learning

Machine Learning and Deep learning (40%)

- Alternation theory / practice in the form of BE (*Bureau d'étude*)

- Machine Learning
    - Neural networks
    - Backpropagation
- Deep Learning
    - Auto-encoders
    - Recurrent neural networks
    - Convolutionnal neural network and transfer learning
    - Attention models and Tranformers

Project to build an applied course (40%)

- Individual project
- Deepening of a subject chosen freely
- Presentation in the form of an applied course (modalities could be adapted)
    - 5 min of introduction (video)
    - 20 min of practice (notebook)

Class components (lecture, labs, etc.)

- Course: 13% (8 HEE)
- Applied course and evaluation: 37% (22 HEE)
- Online courses: 20% (12 HEE)
- Project to build an applied course : 30% (18 HEE)

Grading

MCQ of theoretical knowledge on AI and Deep Learning: 7 pts

Defense of the project of realization of an applied course : 7 pts
Video on the theoretical part of the applied course : 7 pts
Respect of the deadlines and participation in activities : +/- 2 bonus pts

Course support, bibliography

Tutoriels de Yann Lecun
Machine Learning avec Scikit-Learn - Mise en oeuvre et cas concrets, Aurélien Géron
Deep Learning with Python, Francois Chollet
Pattern Recognition and Machine Learning, Christopher Bishop, Springer, 2006. The best book on Machine Learning, it covers a lot of topics! Freely available online.
Deep Learning, Ian Goodfellow et al., MIT Press, 2016. A reference book on Deep Learning. Freely available online.
Dive into Deep Learning, Aston Zhang et al., 2019 An interactive deep learning book with code, math,...

Resources

Teaching team:
- Catherine SOLADIE
- Simon LEGLAIVE

Size of applied courses : 30 for applieds courses

Software tools and number of licenses needed:
- Jupyter Notebook, python, Pytorch or equivalent (free)

Classrooms:
a. WIFI, Connectic for personal computers

Learning outcomes covered on the course

- Know a wide range of machine learning and deep learning tools for data processing, including massive data (C2.1, C6.3)
- Know the basics of machine learning (C2.1)
- Know how to list and give examples of different machine learning families (C2.1)
- Test, analyze and evolve different machine learning and deep learning algorithms (C1.4, C6.1)
- Evaluate the performance of a machine learning algorithms (C2.2, C3.6)
- Design and propose a data processing software illustrating a specific concept or a specific algorithm of machine learning or deep learning (C1.4, C2.1, C2.2, C6.1, C6.3)

Description of the skills acquired at the end of the course

- C1 Jalon 2
  - C1.4 Concevoir : Rédiger soi-même un cahier des charges ou élaborer une approche agile à partir d'un besoin donné
- C2 Jalon 2
  - C2.1 Approfondir : Approfondir l'ensemble de ses connaissances sur un domaine choisi, via les enseignements de 2A
  - C2.2 Importer des connaissances : Réutiliser concrètement des connaissances issues d'un autre domaine ou discipline dans un problème donné
- C6 Jalon 2
  - C6.1 Résoudre numériquement un problème
  - C6.3 Traiter des données

2EL6100 – Communication Systems Engineering

Instructors : **Haïfa Jridi**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

All communications today (mobile communication, satellites, local area networks, ADSL wired networks, etc.) offer higher bit rates thanks to digital processing whose fundamentals have been stated from the information theory of *Claude Shannon* (1948) based on the the two following principles:

- Source Coding trying to remove unnecessary redundancies in the transmitted messages and to gain in information rates.
- Channel coding to protect the transmission of the compressed information toward the receiver aiming to minimize errors for the detected signal.

For ideal transmission over a Gaussian channel, joint source / channel coding is the appropiate way to approach the theoretical limit of the maximum achievable date rate predicted by information theory.

On the other hand, for a wide spectrum of applications, the channel can be much more restrictive with phenomena such as selectivity, multi-path transmission, the Doppler effect ... However, even for this type of channel, there are, fortunately, other ways of protecting the information (besides channel coding) mainly using the notion of diversity (temporal, spectral, spatial ...)

Quarter number

SG6

Prerequisites (in terms of CS courses)

- Notions of probabilities
- Digital Signal Processing (Fourier Transform, Spectral Analysis)

These knowledges are learned from signal processing (1CC4000) and modelisation (1CC3000) courses.

Syllabus

Part 1 : Information theory

1. What is information? Mutual information? Entropy?
2. Channel capacity
3. Shannon ‘s theorems (channel and source coding)

Part 2 : Source coding

- Codes with fixed and variable lengths
- Huffman codes
- Applications (JPEG, MPEG, MP3, H264)

Part 3 : Redundancy for information protection (Channel coding, Diversity and retransmission protocols)

- Block codes
- Convolutional codes
- Viterbi decoding
- Applications: video broadcasting, mobiles communications, etc.
- To go further: LDPC codes, turbo codes, polar codes, ….
- Diversity concept (temporal, spectral, spatial, cooperation)
- Retransmission protocols (ARQ, HARQ, IR)

Class components (lecture, labs, etc.)

The fundamentals are presented in lectures with specific examples. Exercices ensure a good understanding of the course and correct the misinterpretations of the course. Personal works are additional courses requested from students (applications and extensions).

Grading

Final exam : coefficient 0,5 Laboratory exam : coefficient 0,25 Personnal work : coefficient 0,25 In case of a justified absence to one of the intermediary examinations, the grade of this latter is replaced by the grade of the final examination.The grade of the laboratiry exam is based primarily on the level of involvement provided during the sessions and secondarily on the mandatory report.

Course support, bibliography

- Lectures notes provided to students
- G. Battai, "*Théorie de l'information - Application aux techniques de communication*", Ed. Masson, 1997.
- W. Peterson, E. Weldon, "*Error corrcting codes*", Ed. MIT Press, 1972.
- S. Lin, D. Costello, " *Error control coding: Fundamentals and Applications*", Ed. Prentice Hall, 1983.
- G. Cohen, J. L. Dornstetter, P. Godlewski, "*Codes correcteurs d'erreus*", Ed. Masson, 1992.
- J. Proakis, "*Digital communications"*, 4e édition, Ed. McGraw-Hill, 2001.
- J. C. Bic, D. Duponteil, J. C. Imbeaux, "*Eléments de communications numériques*", Ed. Dunod, 1986.
- R.Boite, M. Kunt, "*Traitement de la parole*", Ed. Polytechniques et Universitaires Romandes, 1987.
- J. Deller, J. Hansen, J. Proakis, "*Discrete time processing of speech signals*", Ed. IEEE Press, 1999.
- T. M. Cover, J. A. Thomas, "*Elements of Information Theory*", Wiley New York, 1991.

Resources

- Teaching staff (instructor(s) names): Haïfa Farès, Yves Louët, Georgios Ropokis.
- Maximum enrollment (default 35 students): 20
- Software: MatLab
- Equipment-specific classrooms

Learning outcomes covered on the course

The first objective of this elective is to provide elements regarding the information theory by covering channel and source coding. The second objective is to detail what a digital transmission is and what are the different requirements to target expected performance.

For instance, the students will be able to:

- understand a digital communication chain
- understand the different chain blocks
- understand the metrics of performance evaluation of a digital transmission
- optimize the dimensioning of a transmission chain under constraints (performance trade-offs)
- generate, analyze, process digital signals with Matlab

Description of the skills acquired at the end of the course

In terms of skills:

- The first three course outcomes aim to acquire the C1.2 skill "**Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem**"
- The outcomes 4 and 5 contribute to the core of C1.3 skill "**Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation**"
- The outcome 5 adresses the C1.4 skill "**Design, detail and corroborate a whole or part of a complex system**"
- Tutorials and personal work contribute to develop both C8.1 skill **"Work collaboratively in a team**" and C3.1 skill "**Be proactive and involved, take initiatives**"
- The personal work, for instance, helps to deepen the C7.1 skill **"Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. Highlight the added value**"

2EL6110 – Advanced computer networks

Instructors : **Jean-Francois Lalande**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

This elective course is part of the InfoSec Track, but is accessible to any 2nd year student validating the prerequisites. It aims to present advanced concepts of Computer Networks architecture and is based on the fundamental concepts presented in the elective course "Network and Security " of 1st year.
The classic paradigms of Computer Networks related to the creation of Internet (layered models, TCP/IP protocols, client/server model, etc.) have become widely adopted. However, changes in user needs in terms of data availability and volumetrics as well as the emergence of new applications and new services (support of "heavy" applications as Wep Apps, Cloud Computing, cryptocurrency, etc.) lead to significant changes in traditional architectures of Information Systems. These architectural evolutions, as well as the rise of associated technologies, can also be explained by two current trends:
- The outsourcing of network and hosting infrastructures, and even of applications themselves;
- The optimisation of the use of these infrastructures.

This implies in particular:
- Dynamic, on-demand adaptation capabilities, including the ability to distribute storage and processing but also to quickly reconfigure infrastructures;
- Resource sharing capabilities (compute, storage and network), generally based on the virtualization of infrastructures;
- The use of decentralized, peer-to-peer models;
- Scalable resource allocation models, etc.

Quarter number

SG6

Prerequisites (in terms of CS courses)

1CC1000 – Information Systems and Software Development
1EL6000 – Computer Networks and Security

Syllabus

Lessons 1 to 5 (7,5h):
- Cloud computing
- Data center networks
- Software-Defined Networking (SDN)
Lessons 6 and 7 (3h):
- IPv6
Lab (3h):
- IPv6
Lessons 8 and 9 (3h):
- Distributed Architectures (Cluster)
- Distributed File Systems
- Cluster Management, 0rchestration

- Load Balancing
Lessons 10 and 11 (3h):
- Message queuing systems

Laboratory study (15,5h): implementation of a software network and a distributed service with OpenStack

Class components (lecture, labs, etc.)

A large place is left to practical aspects.
The lectures are punctuated with demonstrations and manipulations.
A long-term laboratory study, including a part of homework, makes it possible to gradually implement the technologies presented in classroom.

Grading

Final written exam: coefficient 0.5. Defence of the laboratory study: coefficient 0.5.
The lab study is always taken into account in the final mark (N1), even if it is lower than the mark of the written exam.

Course support, bibliography

- Teachers Slides
- Paul Goransson, Chuck Black, Timothy Culver, « Software Defined Networks A Comprehensive Approach", 2nd Edition, Morgan Kaufmann
- William B. Norton, The 2014 Internet Peering Playbook: Connecting to the Core of the Internet

Resources

Software tools used on the students' PCs (all free and multi-platform): VirtualBox, OpenVPN client, SSH graphical connection;
Software tools introduced or used (all under free license): OpenLDAP, OpenStack, Open vSwitch, HAProxy, ONOS/OpenDaylight, RabbitMQ...
Hardware platform: 5-server OpenStack cluster, accessible via VPN.

Learning outcomes covered on the course

At the end of this course, students will be able to:
- design an architecture based on an Infrastructure as a Service;
- deploy an IPv6 network using dedicated address attribution mechanisms;
- deploy and configure a message broker for distributed applications;
- explain the principles of elasticity and resource management in Cloud Computing;
- explain the principles and pro & cons of resource virtualization;
- explain the principles of peer-to-peer networks for data exchange or Blockchain management.

Description of the skills acquired at the end of the course

C1.1 - Analyze: study a system as a whole, the situation as a whole. Identify, formulate and analyze a system within a transdisciplinary approach with its scientific, economic, human dimensions, etc.
C2.1 - Deepen a field of engineering sciences or a scientific discipline
C7.1 - Know how to convince: Structure ideas and arguments, be synthetic (assumptions, objectives, expected results, approach, and created value)

2EL6120 – Intelligent Wireless Access & Experimentation

Instructors : **Haïfa Jridi**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The scope of the course is to present the essential knowledge necessary to understand the characteristics of wireless communications systems and standards. To this end, the course focuses on some of the several aspects of communications systems including:

1. transmission technologies used in current and future standards, including 4G and 5G
2. Multiple Access technologies used in current and future standards (starting from 2G and moving to 5G and beyond 5G),
3. the basics and characteristics of telecommunications hardware including the architecture of computing equipment used in communication and the behavior of RF chains,
4. architectures of mobile processors
5. the process of experimentation and prototyping for wireless communications systems.

The course covers all the technical essentials for students that are interested in understanding the fundamentals of wireless communications and its applications, and can serve as a first step for those interested in taking further studies in wireless communications engineering. Moreover, as the course exposes students to several aspects of wireless communications engineering, it serves as an excellent opportunity for those of them interested in pursuing a career in project/team management in the broad area of Communications Engineering. The course will help students familiarising with the most significant aspects of Wireless engineering including wireless communications standards and their characteristics, wireless hardware and prototyping. The presentation of the material will follow a standard oriented approach such as to cover students interested both in the fundamentals of Wireless Communications as well as students mostly interested in a more applied approach to Wireless Communications.

Quarter number

SG8

Prerequisites (in terms of CS courses)

1. Notions of probabilities
2. Digital Signal Processing (Fourier Transform, Spectral Analysis)
3. Basic programming skills

These presrequisites correspond to signal processing (1CC4000),modelisation (1CC3000) and programming (1CC1000) courses.

Syllabus

Part 1: Fundamentals of Wireless transmission

- Physical modelling of wireless channel
- Detection in a fading channel
- Digital Single Carrier and Multicarrier modulation
- Diversity techniques

Part 2: Multiple Access Schemes and Standards : (Multiple Access Schemes for 2G, 3G, 4G, 5G and Beyond 5G networks).

- TDMA, FDMA, CDMA, SDMA
- FDD, TDD, half duplex and full duplex
- Interference management
- Applications in GSM/UMTS/4G/5G network standards
- Other wirless access standards: WLAN, WPAN and LPWAN
- IoT standards and connected objects

Part 3: Computing architectures for wireless communications

- Adaptable wireless communications architecture: the Software-Defined Radio (SDR)
- Analog/Digital front-ends and ADC/DAC data converters
- Embedded computing architectures: from mobile ARM processors to DSPs, FPGAs and GPUs
- Embedded computing platforms for wireless communications

Part 4: Hardware implementation fon wireless systems using GNU Radio and USRP platforms

- Tutorial on GNU Radio
- Implementation of a simple FM receiver
- Implementing a file transfer application on GNU Radio and USRP with QPSK based modulation and demodulation

Class components (lecture, labs, etc.)

Course layout, course organization (CM, TD, EL / TP sequencing) in hours:
Fundamentals of Wireless Communications Lectures: 4,5h
Multiple Access Schemes and Standards Lectures: 4,5h
Practical work on Fundamentals of Wireless Communications and Multiple Access Schemes: 4,5h
Computing Architectures for Wireless Communications CM: 6h

GNU Radio tutorial CM: 1.5h
Experimentation/Practical work using GNU Radio and USRPs : 9h
Exam: 30min (MCQ)
Total (HPE): 30,5h

Grading

Final (written) exam and evaluation of practical/laboratory work

Course support, bibliography

- Handout provided to students
- Tse, D., & Viswanath, P., “Fundamentals of Wireless Communication”. Cambridge: Cambridge University Press, 2005.
- Holma H., & Toskala A., “LTE for UMTS: OFDMA and SC-FDMA Based Radio Access”, Wiley Publishing, 2009.
- Vaezi M., Ding Z., & Poor H. V., “Multiple Access Techniques for 5G Wireless Networks and Beyond”, Springer 2018.
- Yannick Bouguen, Eric Hardouin, François-Xavier Wolff, “LTE et les réseaux 4G”, Eyrolles, 2012
- A. Elnashar, M. A. El-saidny, M. Sherif, K. Abdulla, “Design, deployment and performance of 4G networks”, Wiley-Blackwell 2014,
- Fattah Hossam, “5G LTE narrowband Internet of Things (NB-IoT)”, CRC Press in 2019.
- A. Pacaud, “Électronique radiofréquence”, Ellipses, 2000,B. Razavi
- “RF microelectronics, communication electronics”, Prentice Hall, 1997

- P.L.D. Abrie, “Design of RF and microwave amplifiers and oscillators”, Artech House, 1999,
- S.C. Cripps, “RF power amplifiers for wireless communications”, Artech House, 2006,
- Gernot Hueber, Robert Bogdan Staszewski “Multi-Mode/Multi-Band RF Transceivers for Wireless Communications: Advanced Techniques, Architectures, and Trends” , John Wiley & Sons, Inc, 2010
- Peter B. Kenington, ” RF and Baseband Techniques for Software Defined Radio ", Artech House, 2005.
- Collins, T.F.; Getz, R.; Pu, D.; Wyglinski, A.M. Software-Defined Radio for Engineers; Artech House: Norwood, MA, USA, 2018.

Resources

- Teaching staff (nales of professors delivering lectures): Haïfa Farès, Amor Nafkha
- Size of TD (by default 35 students): 20
- Software tools and number of required licences: MATLAB and GNU radio for practical and personal work
- Practice rooms (deparment and capacity):

Learning outcomes covered on the course

At the end of the course, the students should be able to:

- understand the basics of digital transmission and multiple access schemes used in existing standards
- understand how a complete wireless communications RF chain works (Radio, Analog and Digital domains)
- become familiar with several different digital processing platforms available for building wireless communications systems and their impact on system requirements (cost, performance, lifetime, energy efficiency etc)
- understand the terminology, structure and characteristics of modern wireless and mobile communications standards
- experiment on building a real wireless communication system

Description of the skills acquired at the end of the course

The course addresses the folowing skills

1. C1.2 skill "Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem"
2. Tutorals and practical work address:
    a. The C1.4 skill "Design, detail and corroborate a whole or part of a complex system"
    b. Core Skills "C3.1-Be proactive and involved" and "C8.1-Work collaboratively in a team"

2EL6130 – Embedded systems and internet of things

Instructors : **Ruben Salvador Perea**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

This elective course is part of the Infosec track, but can be taken by any second year student that knows how to program in C and Java. The goal of this elective course is to discover the specificities of the development of applications that are executed on embeded systems or IoT objects.

The constraints for developing these connected objects are multiple: energy limits, computing capacities, network connectivy, data overloading, real time, etc. Indeed, this elective course will focus on general principle that are shared by these devices, ofr example, the data upload to the cloud, the optimization of the software computing, the network connectivity.

In a second part, the elective course illustrates these principles by selecting real embedded systems on which we study the software ecosystem. From the language point of view, the course shows how can be used the C language.

Quarter number

SG8

Prerequisites (in terms of CS courses)

- Know programming with the C language
- Know the basics of Linux command lines

Syllabus

CM 1-2 Introduction to embeded systems and IoT
CM 3-4 Real-Time systems
CM 5-6 RIOT et IoT networks
CM 7-8 Getting started with RIOT
CM 9-10 Getting started with FreeRTOS

TP 11-14 RIOT
TP 15-18 FreeRTOS

Class components (lecture, labs, etc.)

- 15h of lectures
- 12h of labs

Grading

- Continuous control: Evaluation of labs (0.5)
- Continuous control: Presentation of advanced topics (0.5)

Resources

- Emulators or real devices
- Platform IoT Labs

Learning outcomes covered on the course

- Know the specificities and the constraits of embedded systems et internet of things
- Develop software with such systems

Description of the skills acquired at the end of the course

- C6.3 Specify, develop et realize and validate a software

2EL6140 – Microgrids : components and control

Instructors : **Pierre Haessig**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The supply of electricity to isolated sites such as islands has some specific characteristics due to the small size of their power grid. This leads to a high risk of instability and therefore the control of a microgrid, including all its electrical components, is crucial for its proper operation.

This elective proposes to study this issue from two perspectives:

- **Electrical engineering**: presentation of the key electrical components of an alternating microgrid
- **Automatic control**: implementation of control techniques on these components and introduction to the control of large-scale systems (i.e. how to go beyond the “classical” control theory which only deals with 2–3 variables).

Note: the electrical engineering program of this elective is close to the “Energy Conversion” elective offered in Paris-Saclay. The automatic control part is unique to this elective.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Power systems concepts you need to know (e.g. by having taken the first-year elective “Electrical Energy (ENE)”):

1. Power in AC regime: P (active), Q (reactive) and S (apparent)
2. **Three-phase** electric power system: phase-to-neutral and phase-to-phase voltages

Control theory concepts you need to know (e.g. by having followed the ST5 common course on control theory):

- Modeling a system by a transfer function
- Regulation of a linear system by a PID controller

Having taken the ST7 “Smart grids and energy challenge: energy management in isolated sites” would be a plus, but is not a prerequisite, as the topics addressed are very different:

- ST7 “Renewable energies and microgrids” course: high level modeling (energy flows), with economic optimization.
- this elective: voltage/current modeling and more detailed analysis of electrical components and their low-level regulation.

Syllabus

This elective belongs to both *electrical engineering* and *automatic control*, with extra *transversal and practical* skills on the analysis and control of systems thanks to the intensive use of a modeling and simulation software.

For the electrical part, the aim is to understand the operation and modeling of the *energy conversion components* of a microgrid:

- power electronics converters (choppers and inverters)
- AC electric machines (synchronous and asynchronous)

This knowledge is presented through lectures and exercise sessions.

For the automatic control part, the aim is to understand the *control and regulation* strategies of microgrid components, in particular the power electronics converters. In addition, this part includes an introduction to the control of large-scale systems (the microgrid with its many components).

This automatic control part is mainly conducted as hands-on sessions on computers. These sessions are an opportunity to *intensively practice* a modeling and simulation tool (Simulink/Simscape). One of the issues addressed is the choice of a level of details in the model adapted to the objective (compromise between simplicity, speed, fidelity…). This transversal skill is meant to be transposable to other engineering fields.

Note: the optimization of power flows (power dispatch) to ensure the economically optimal operation of a microgrid is not addressed. Indeed, this issue is part of the ST7 optimization project. “Smart grids and the energy challenge: energy management in isolated sites”.

Class components (lecture, labs, etc.)

Lecture sesssions aim at acquiring basic knowledge in the field of power systems. These sessions include exercises on paper.

The practical sessions are done on computers (Matlab/Simulink). Computer work can be done in pairs. The time devoted to these sessions is substantial to allow the students to become fully comfortable with the simulation tool.

Lectures: 9 hours, Tutorials: 9 hours, Laboratories: 15 hours, Evaluation (written exam): 2 hours.

Grading

The evaluation of the lecture sessions is one final written exam.

The evaluation of the computer lab sessions is done by checking the progress along the sessions and by a final synthesis report.

The weighting between the lecture part and the practical part is 50%, 50%.

Course support, bibliography

Course site on Edunao: https://centralesupelec.edunao.com/course/view.php?id=1494

Resources

Course staff:

- Pierre Haessig: course supervisor
- Alexandros Charalampidis: computer lab sessions
- Loïc Matel: electric machines & power electronics lectures

Required software: Matlab, with Simulink and the Simscape Electrical toolbox. Academic licenses for those products are free for all CentraleSupélec students.

Learning outcomes covered on the course

At the end of the lectures, students will be able to:

- *Describe the operation* and *perform simple theoretical analyses* of the electrical machines and power electronic converters covered in the course

At the end of the practical part, students will be able to:

- *Implement* models of electronic converters in a simulator (Simulink) with a complexity adapted to the phenomena to be studied.
- *Describe* the control structure of an electronic converter and *adjust* some control loops of this structure.
- *Evaluate/analyze* the proper operation of the regulation through well-selected simulations

Description of the skills acquired at the end of the course

The learning outcomes of this course allow validating the following CentraleSupélec engineer core skills:

- C1.2 Use and develop appropriate models, select the appropriate modeling scale and relevant simplifying assumptions to tackle a problem
- C1.3 Apply problem-solving through approximation, simulation and experimentation
- C1.4 Specify, design, build and validate all or part of a complex system

2EL6150 – Model-based predictive control

Instructors : **Romain Bourdais**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

Model Predictive Control (MPC) is the advanced control technic the most used for engineering systems. Its industrial use is booming because it optimizes the operation of an industrial process, its energy efficiency while integrating operating constraints. However, it is still the subject of a large number of scientific publications, even if the last concerns of the scientific community remain very theoretical.

This course presents the main principles of the predictive control in a precise, readable and intuitive mathematical formalism and which is not reserved for the automation engineers - *The predictive control will be treated in depth and in all the aspects of the automatic in the mention of 3rd year "Control Engineering"* - After an introduction to the basic concepts of the MPC, this course is built around many case studies, where they will be applied both in simulation and in practice for different industrial processes. In this course, it is therefore a question of providing decision and control tools that exploit a model of the system in order to improve its efficiency. Expectations in terms of efficiency are translated into a mathematical multicriteria that must be minimized. The model can be derived from a mathematical representation of the considered system, in which case conventional methods (deterministic, linear programming for example, or explicit resolution) of optimization can be used. The optimization process can also use a simulator of the studied system, which must then use heuristic techniques.

Applications will focus on control under energy constraints (limited power, demand for load shedding, etc.) and on the use of such techniques for sizing energy production or storage systems.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Control Theory Course
Optimisation Course

Syllabus

An Introduction to Model Predictive Control (15h of lectures, 9h of Laboratory Work)

- Basis concepts
  - Prediction model
  - Receding horizon principle
  - Specifications and mathematical translation of objectives
  - Optimization problem solving and closed-loop behavior
  - Tuning
  - Explicit and Implicit solving
- Economic MPC
- Constraints Integration

Challenge: How to improve the energy efficiency of a building: a combination of renovation and active piloting (6 hours set aside in the timetable, +12 hours of independent work). This case study integrates an economic dimension with risk-taking in terms of managing uncertainties.

1. Data analysis and literature review
2. Integration of uncertainty (meteorological phenomena, random consumption)
3. Trade-offs: investment in infrastructure and high-performance active control capability
4. Calculation of return on investment
5. Comfort assessment (demand satisfaction)
6. Risk analysis
7. Inter-team challenge - Presentation and peer evaluation

Class components (lecture, labs, etc.)

This module is built on very few theoretical courses. Practical work is at the heart of this module, which combines both model experiments (industrial wind tunnel) and technical-economic studies where theoretical content is used as a basis for decision-making.

Grading

- Knowledge test: 30%
- Practical work report: 30%
- Presentation of the challenge: 40%

Course support, bibliography

- Model-based Predictive Control – A practical approach, J.A. Rossiter, CRC Press, 2003
- Model Predictive Control: Theory and Design, J. Rawlings and D. Mayne, Nob Hill Pub, 2009
- Model Predictive Control, E. Camacho and A. Bordons, Springer-Verlag London, 2007

Resources

- Teaching staff (instructor(s) names): Romain Bourdais, Pierre Haessig
- Maximum enrollment (default 35 students): 25 students
- Software, number of licenses required: Matlab/Simulink/Optimization Toolbox
- Equipment-specific classrooms: 25 students, Model Wind tunnel (available on Rennes Campus)

Learning outcomes covered on the course

At the end of this course, the student will be able to

- Specify the technical and economic stakes of the control-command problem under a Model Predictive Control formalism:
    - Choose an optimization criterion
    - Integrate operating and usage constraints
- Choose and use an appropriate optimization tool to solve the predictive control problem under consideration.
- Tune the parameters adapted to the situation and argue about these choices through simulation.
- Master scientific and technical communication (during reports or oral presentations).

Description of the skills acquired at the end of the course

- "Specifying the stakes of the control-command problem under a predictive command formalism" is part of **C1.1 "Examine a problem in full breadth and depth, within and beyond its immediate parameters, thus understanding it as a whole. This whole weaves the scientific, economic and social dimensions of the problem.".**
- "Choosing and using a suitable optimization tool for solving the predictive control problem under consideration" is part of **C1.2 "Select, use and develop modelling scales, allowing for appropriate simplifying hypotheses to be formulated and applied towards tackling a problem".**
- Select and use an optimization tool to solve the predictive control problem under consideration" is part of **C2.3 "Independently identify and acquire new knowledge and skills needed"**

2EL6170 – Production and flow management

Instructors : **Vincent Hovelaque**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **No**

Description

The aim of this course is first of all to introduce students to the main concepts of production and flow management, in order to

- better understand current issues and the role of production management in organizations
- get the same language as business leaders

Its second objective is to familiarize students with the methods and tools applicable to production and flow management, mainly :

1. flow and stock control methods
2. methods for improving industrial performance (lean manufacturing, etc.).

Quarter number

SG8

Prerequisites (in terms of CS courses)

None

Syllabus

- Products and resources, flows and capacity in the company
  - Manage products and resources in the company
    - Managing products: flow decisions
    - Managing resources: capacity decisions
    - Ensure synchronization of flows and capacities over time
  - Data associated with products and resources
    - Technical data
    - Activity data
- Flow and stock control
  - Inventory management
    - Inventory Management Models for Independent Demand
    - Choosing a model
  - Flow planning
    - Comprehensive planning: development of ICP
    - Detailed planning: developing the PDP
  - Flow programming

        - MRPO Logic
        - MRP1 logic: load-capacity matching
    - Flow scheduling
        - Centralized Scheduling
        - Decentralized Scheduling (Kanban...)
    - Demand Driven approaches - a credible synthesis?
- Improvement of industrial performance (lean logic)
    - Measuring industrial performance
        - Calculation criteria
        - SRTs and other indicators
    - The Just-A-Time (lean logic)
        - Actions at the product level
        - Resource actions
        - Actions at the level of relations with partners - link with Supply Chain Management and partnership methods (GPA, GMA, CPFR...) + new tools (Blockhain)

Class components (lecture, labs, etc.)

The course alternates between lectures and tutorials.

Grading

This module will be evaluated by a written exam.

Resources

The course (a mix of lectures and working classes) is given by a team of professors from the Institut de Gestion de Rennes.

Learning outcomes covered on the course

By the end of this course, students will be able to:

1. Establish the links between the Production Management function and, in the broadest sense of the word, logistics with the different departments of the company.
2. Identify the main problems of logistics (especially industrial logistics) in organizations.
3. Use the main methods of stock management and flow control and analyse their consequences for the company.
4. Identify the methods of stock management and flow control best suited to a given environment.
5. Using some productivity indicators in industrial logistics (TRS...)

Description of the skills acquired at the end of the course

C1.1 Examine a problem in full breadth and depth, within and beyond its immediate parameters, thus understanding it as a whole. This whole weaves the scientific, economic and social dimensions of the problem

C2.5 Master the skillset of a core profession within the engineering sciences (at junior level)

C3.7 Make pragmatic and informed choices with the aim of producing tangible results.

2EL6180 – Digital marketing

Instructors : **Maud Daniel Chever**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **No**

Description

The objective of this course is to present the marketing approach and its challenges, and to show the impact of digital transformation on the company and more precisely on the marketing function.

Quarter number

SG6

Prerequisites (in terms of CS courses)

None

Syllabus

Introduction : What is marketing?
Marketing in a context of digital transformation and globalization

I. The fundamentals of marketing
1. Establish a marketing strategy
a. Strategic diagnosis
b. The marketing study
2. Implementing the marketing strategy: the marketing mix

II. The impact of digital on marketing
1. From digitisation to digital transformation: definitions and representations of the digital transformation of companies
2. The use of new technologies to optimize the marketing approach
a) Digitalisation and marketing research
b) Digitisation and marketing mix

The modification of the offer
The co-creation with costumers
Digital promotion
Omnichannel retail

Conclusion

Class components (lecture, labs, etc.)

The various courses are taught by professors and lecturers from the University of Rennes. The concepts seen in

class will be illustrated and put into perspective during a meeting with a digital marketing practitioner (3 hours of intervention by Marianne Auffrey, former marketing manager of the Rennes stadium on digital communication)

Grading

An individual written file will be requested at the end of the module.

Course support, bibliography

Ferrandi F., Lichtlé M.C. (2014), Marketing, Dunod, 352p.

Aurélie Dudezert A. (2018), La transformation digitale des entreprises. Paris, La Découverte, « Repères ». URL : https://www.cairn.info/la-transformation-digitale-des-entreprises--9782348036019-page-57.htm
Hagberg J., Sundstrom M., Egels-Zandén N., (2016) "The digitalization of retailing: an exploratory framework", International Journal of Retail & Distribution Management, 44, 7, 694-712

Resources

The teaching team consists of Maud Daniel and Jacques Diouf, professors at the University of Rennes 1.

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Establish the strategic diagnosis/marketing of a brand/brand
- Know how to build and implement a marketing action plan
- To know how to situate a company's strategy in a context of digital transformation
- Optimize the use of new technologies in the implementation of marketing strategy

Description of the skills acquired at the end of the course

C4.1 : Think in client terms, identify and analyse customer needs, the constraints of other stakeholders as well as include societal challenges.
C7.4 : Master spoken, written and body language, as well as basic communication techniques.

2EL6190 – Bayesian methods for machine learning

Instructors : **Simon Leglaive**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Bayesian modeling, inference and prediction techniques have become commonplace in machine learning. Bayesian models are used in data analysis to describe, through latent factors, the generative process of complex data (medical images, audio, documents, etc.) The discovery of these latent or hidden variables from observations is based on the notion of posterior probability distribution, the calculation of which corresponds to the Bayesian inference step.

Let's take the example of a technique called "Latent Dirichlet Allocation" or LDA. This is a Bayesian method, which in particular is used to discover hidden topics in a set of observed documents. If we apply this technique to analyze a set of 1102 abstracts of scientific articles on Bayesian machine learning published in *Journal of Machine Learning Research (JMLR)*, the following topics emerge:

Topic #1: model models data process latent bayesian dirichlet hierarchical nonparametric inference
Topic #2: features learn problem different knowledge learning image object example examples
Topic #3: method neural bayesian using linear state based kernel approach model
Topic #4: belief propagation nodes local tree posterior node nbsp given algorithm
Topic #5: learning data bayesian model training classification performance selection prediction sets
Topic #6: inference monte carlo markov sampling variational time algorithm mcmc approximate
Topic #7: function optimization algorithm optimal learning problem gradient methods bounds state
Topic #8: learning networks variables structure network bayesian em paper distribution algorithm
Topic #9: bayesian gaussian prior regression non estimation likelihood sparse parameters matrix
Topic #10: model information bayesian human visual task probability sensory prior concept
(credits: Rémi Bardenet, https://github.com/rbardenet/bml-course/blob/master/notebooks/00_topic_modelling_for_Bayesian_ML_papers.ipynb)

Recognizable topics stand out, such as *Topic #6* on approximate Bayesian inference methods or *Topic #8* on learning in Bayesian networks.

The Bayesian machine learning approach has the advantage of being interpretable, and it makes it easy to include expert knowledge through the definition of priors on the latent variables of interest. In addition, it naturally offers uncertainty information about the prediction, which can be particularly important in certain application contexts, such as medical diagnosis or autonomous driving for example.

This course is built as a "journey towards variational autoencoders (VAEs)". Introduced in 2014, VAEs lie at the intersection of Bayesian modeling and inference techniques and deep learning with artificial neural networks. This type of model is at the heart of many current challenges in artificial intelligence (weakly-supervised learning, causality, etc.). The different sessions of this module aim at introducing fundamental notions allowing at the end an in-depth understanding of VAEs, while remaining generalizable to many other application contexts. After two sessions on the fundamentals of the Bayesian methodology and machine learning, we will study Bayesian networks and exact inference techniques for latent variable models. As exact inference is not always possible, we will move on to approximate techniques based on variational and Markov chain Monte Carlo (MCMC) methods. We will end with deep-learning-based generative models, exploiting recent variational inference methods that scale for large datasets or for high-dimensional data

Theoretical concepts will be applied on concrete data, in particular during lab sessions in Python. Different supervised and unsupervised Bayesian learning models will be implemented (Gaussian mixture model, Bayesian and sparse linear regression, variational autoencoder). These examples will allow the students to study the influence of the prior on the parameters of the model and on the obtained prediction compared to a non-Bayesian approach.

Quarter number

SG6

Prerequisites (in terms of CS courses)

Basics of statistics and probabilities. Fundamentals of machine learning: empirical risk minimization, maximum likelihood approach, supervised learning (linear models for regression and classification), unsupervised learning (dimensionality reduction, clustering). The 1st-year course "statistics and learning" provides all these requirements.

Syllabus

Lectures:

- Fundamentals of Bayesian modeling and inference
- Fundamentals of machine learning
- Bayesian networks and inference in latent variable models
- Variational inference
- Markov Chain Monte Carlo
- Deep generative models

Lab sessions:

1. Gaussian mixture model
2. Bayesian linear regression

Class components (lecture, labs, etc.)

The course is organized in 7 lectures of 3 hours, 3 lab sessions of 3 hours on Python, and 1 revision session. Most of the lectures also include a short practical session (in Python) to apply the theoretical concepts. Students will be asked to do theoretical preparatory work before the lab sessions.

Grading

The theoretical preparatory work before the lab sessions and the completed Jupyter notebooks will be evaluated and count for 30% of the final grade. The remaining 70% correspond to a 2-hour final exam.

Course support, bibliography

Course materials (slides, Jupyter notebooks, Python code and teaching activities) will be made available on Edunao.

References:

- Christopher M. Bishop, « *Pattern Recognition and Machine Learning* », Springer, 2006 (freely available online)
- Marc Peter Deisenroth, A. Aldo Faisal, and Cheng Soon Ong, « *Mathematics for Machine Learning* » Cambridge University Press, 2020 (freely available online)
- Kevin P. Murphy, « *Machine Learning, A Probabilistic Perspective »,* MIT Press, 2012 (available at the library)

Resources

Teaching team: Simon Leglaive
Software tools: Anaconda (Python package manager).

Learning outcomes covered on the course

At the end of the course, students are expected to:

- know when it is useful or necessary to use a Bayesian machine learning approach;
- have a view of the main approaches in Bayesian modeling and inference;
- know how to identify and derive a Bayesian inference algorithm from the definition of a model;
- be able to implement standard supervised or unsupervised Bayesian learning methods.

Description of the skills acquired at the end of the course

C1. Analyze, design, and build complex systems with scientific, technological, human, and economic components
C6. Be operational, responsible, and innovative in the digital world

2EL6200 – Advanced corporate finance

Instructors : **Maxime Guymard**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **Yes**

Description

The course first allows you to deepen the financial management of a company after the initiation course of the first year. Secondly, the course aims to give a broader understanding of the world of finance, by understanding the functioning of the financial system, its role, its history and the main actors intervening in this sector.

Quarter number

SG8

Prerequisites (in terms of CS courses)

Business Management (1st year)

Introduction to Corporate Finance (1st year)

NB: students who have taken the 2A Corporate Finance and Law elective on the Gif campus (December-January period) are advised not to also take this Advanced Corporate Finance elective. Although the scope of this Advanced Corporate Finance course is broader, there would be significant duplication in the core part of the course.

Syllabus

1. First, the core lectures:
- In-depth study of accounting basics: balance sheet, income statement (P&L), cash flow statement
- Solvency
- Profitability (ROCE, ROE)
- Weighted Average Cost of Capital (WACC)
- Financial criteria to select an investment (NPV, IRR)

2. Once the core lectures mastered:

- Business Valuation
- Start Up financial management
- Bankruptcy and restructuring
- Introduction to Market Finance (stocks, bonds, derivatives)
- Understanding of the role of some key players in the financial world (Banks, Insurance, Rating Agencies)
- History of finance

Class components (lecture, labs, etc.)

Integrated lectures mixing theory and tutorials (9.5 * 3h); Final Exam (2h). The integrated class consists of alternating on the same slot lecture course, simple application exercise and more complex case study (TD). Some (few) sessions can be done remotely via Microsoft Teams.

Grading

The assessment will consist of 3 parts:
o Teamwork: Short oral presentation to the whole group on a subject on the history of finance or key players in the financial world (20% of the grade)
o Teamwork: Financial analysis of a company of your choice, delivery of a written note (20% of the note)
o Individual work: assignment on a final evaluation table of 2 hours, consisting of course questions, application exercises and a case study (60% of the mark)

Course support, bibliography

- Corporate Finance. Pierre Vernimmen, Pascal Quiry, Yann Le Fur.

1. La gestion financière de l’entreprise. Christian Pierrat
2. Manuel de Finance d’Entreprise. Georges Legros
3. Dessine-moi la comptabilité. Isabelle de Kerviller

Resources

Teacher: Maxime GUYMARD

Learning outcomes covered on the course

At the end of this module, the student will be able to:
- Read and interpret a company's financial statements
- Carry out the financial analysis of a company
- Estimate the valuation of a company
- Determine on quantifiable financial criteria whether a project should be undertaken or not
- Mobilize knowledge of the financial world (professions, actors, history) to understand corporate finance problems

Description of the skills acquired at the end of the course

C3- Act, undertake, innovate in a scientific and technological environment
C4 - Have a sense of value creation for his company and his customers

2EL6210 – Geopolitics of resources and objects

Instructors : **Raphael Danino-Perraud**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,50**
Elective category : **Business Sciences**
Advanced level : **No**

Description

In their future careers as engineers, CentraleSupélec students will be called upon to place their practices in globalized economic and political worlds. These are characterized by the interconnection of different parts of the globe and an intensification of the flow of capital, goods and services on a global scale, made possible in particular by the development of means of transportation and information and communication technologies. Although globalized production and exchange networks appear to be free of all material constraints, they remain highly dependent on natural resources and technical objects.

Since the end of the 20th century, human activities and their impacts (urbanization, climatic and environmental changes) have contributed to increasing the pressure on resources and their availability. The geopolitics of resources and objects influences international power relations and raises power issues at various scales (local, national, regional, global).

To understand the stakes of our globalized political and economic system, we must therefore adopt a critical reading of techniques and resources. To do so, we adopt a perspective centered on a certain number of resources (mining, agricultural and energy, but also waste) and infrastructures (pipeline, electrical network, hydroelectric dam). It is from these geopolitical themes that students will be led to identify the power relationships between actors and the economic stakes associated with them.

Quarter number
SG6

Prerequisites (in terms of CS courses)

None

Syllabus
Detailed course outline (content): 11 sessions of 3h, 1 exam of 1h30
Session 1 - Introduction: a brief epistemology of resources - Raphaël Danino-Perraud and Angélique Palle (TD)
Session 2 - A transnational energy transport infrastructure as a geopolitical object - Noémie Rebière (CM)
Session 3 - Methodology of geopolitical mapping - Léa Gobin and Noémie Rebière (lab)
Session 4 - Geopolitical impacts induced by the energy transition: risks on objects and resources circulation - Angélique Palle (CM)
Session 5 - Project support - Raphael Danino-Perraud and David Juilien (PT)
Session 6 - Applied exercise: role-playing - Wahel Rashid and David Juilien (PT)
Session 7 - Producing and feeding ourselves: conflicts over resources - Matthieu Brun (CM)
Session 8 - Hydroelectric dams, a geopolitical object - David Juilien and Wahel Rashid (TD)
Session 9 - Mineral raw materials, globalized resources: the example of lithium - Audrey Sérandour (CM)
Session 10 - Waste, a geopolitical object - Wahel Rashid and Raphaël Danino-Perraud (TD)
Session 11 - The contrasting application of the duty of care for resources and conclusion of the course - Raphaël Danino-Perraud (CM)

Session 12 - Homework (1h30)

Grading

Student learning will be assessed in two ways:

1. A cartographic analysis file, carried out in groups (of 3-4 students) equivalent to 50% of the grade. Throughout the sequence, students will have to build a geopolitical reflection around a resource or a globalized object. They will have to identify the main actors and issues raised by this resource or object, take a critical look at the materiality of the resources and techniques studied (no technology is neutral) and construct a reflection at different scales (global, regional, national, local).
Based on a bibliographic research, students will have to produce two analytical maps presenting a geopolitical reasoning around a globalized resource or object. At least one of the two maps must be produced on a global scale. The supervision of this work will begin during the session on the methodology of geopolitical cartography (session 3), then we will have a session dedicated to the accompaniment of projects (session 5).
The restitution will take the form of a written file, including the two maps, a description of the problematized legend (in 1 page) and an analysis of the maps (in 5 pages maximum). This written report will be graded. Follow-up on the project will be organized during the semester through presentations on the state of the art (not graded).

2. A table-top assignment, carried out in session 12 (duration: 1h30) equivalent to 50% of the grade. This will consist of a commentary on documents (a corpus composed of excerpts from articles, a map and a graph). The corpus will present a case study, which will be analyzed by mobilizing the concepts studied in class.

Course support, bibliography

- ABIS Sébastien, BRUN Matthieu (2020), « Géopolitique de l'agriculture européenne », Études, 2020/2 (Février), pp. 17-28.
- LACOSTE Yves (2008), « La géographie, la géopolitique et le raisonnement géographique », Hérodote, 2008/3, n°130, pp.17-42. [En ligne] URL : https://www.cairn.info/revue-herodote-2008-3-page-17.ht m
- PITRON Guillaume (2018), La guerre des métaux rares : la face cachée de la transition énergétique et numérique, Paris, Éditions Les liens qui libèrent, 296 pages.
- REBIERE Noémie, « Énergie et géopolitique régionale : quel avenir pour le hub turc ? », Orients Stratégiques (n°6), L'Harmattan, Paris, 01/2018, pp.1-15.
- ROTILLON Gilles (2010), Économie des ressources naturelles. Collection Repères, Paris, Édition La Découverte, Collection Repères,128 pages.

Resources

Teaching team: Raphaël DANINO-PERRAUD (PhD in economics, French Ministry of Defence), David JUILIEN, Wahel RASHID, Audrey SÉRANDOUR, Matthieu BRUN, Léa GOBIN, Angélique PALLE, Noémie REBIERE

Learning outcomes covered on the course

At the end of this course, students will be able to :
- adopt a critical view of resources, discuss the issues of access, distribution and control of these resources, and problematize the issues raised by their exploitation and circulation;
- have factual knowledge on a variety of case studies, located on several continents (Europe, Asia, Latin America) and analyzed at various scales (global, regional, national, local);
- master the basics of the geopolitical analysis method and its key concepts (actors, power relations, representations, territories). He will be able to identify the relevant actors and detect the power relations crystallized around a resource or an object, at various scales;
- read a map and understand it from a geopolitical and critical perspective. They will also have acquired the basics of freehand cartography.

Description of the skills acquired at the end of the course

analyze: study a system as a whole, the situation as a whole. Identify, formulate and analyze a system within the framework of a transdisciplinary approach with its scientific, economic, human dimensions, etc.
C2.2: Import knowledge from other fields or disciplines
C5.3 : Analyze global and/or local issues at the international level and adapt projects or solutions to them

SCIENCE AND ENGINEERING CHALLENGE N°5 COURSES

ST5 - 51 - PILOTING AND FLIGHT CONTROL IN AERONAUTICS AND SPACE TRANSPORTATION

Dominante : GSI (Large Interacting Systems) and CVT (Construction, City and Transport)

Langue d'enseignement : French

Campus où le cours est proposé : **Paris-Saclay**

Engineering problem

This sequence addresses the problem of designing flight control laws and dynamic control of vehicle flight (aircraft, satellite and launcher). It aims to give students the basic concepts associated with the design of control systems of a flying object around its 6 degrees of freedom in order to ensure stability of operation and the required performance. The technologies in the fields of aeronautics and space being in constant evolution (propulsion, structure, materials, etc.), the laws of piloting must adapt to guarantee the best performances while taking into account the new constraints, in particular regulatory, environmental and economic.

The integration course allows students to apply the skills and knowledge acquired in the case of an aircraft, a nanosatellite and/or a launcher. These vehicles have become very popular in recent years due to the reduced cost associated with their construction and operation. However, it raises new problems, in particular for the control of attitude and performance due to the miniaturization of the components and thus the reduction of their capacities of action and their effectiveness.

The intervention of industrialists from the aeronautics and space sector in this sequence allows a better understanding of the issues associated with the design and operation of increasingly constrained systems.

Adviced prerequisites

Two main topics are covered in this sequence: modeling of undeformable objects and modeling of linear systems (transfer functions, state representation, differential equations) for control. These recommended prerequisites are part of the common course of Modeling (ST2) and the SPI course of Mechanics and Continuous Media. The rest of the necessary skills are based on the capitalization of CPGE knowledge and self-training.

Context and issue modules:

The introduction of the sequence is organized around three half-days of training aiming at presenting the sequence, the integration teaching and introducing the stakes of the various sectors of space and aeronautics, according to several actions such as:

- Presentation of the thematic sequence and introduction to the integration lessons
- Conferences on the civil and military aeronautics sector: from the design of airliners to operations and traffic management (example of speaker: Air France, Dassault Aviation)
- Conferences on applications and uses in space (example of speakers: CNES, Thalès Alinea Space)
- Introductory conference on the law of space activities (speaker: Institut du Droit de l'Espace et des Télécommunications, IDEST). Introduction to the concepts of space surveillance (speaker: ArianeGroup). Conference on the economy in space (speaker: CNES).
- Conference on sustainable development in aeronautics and space (example of speakers: Safran, Parrot, ESA).

Specific course (60 HEE) : Performance and flight trajectories

Brief description :

The objectives of this specific course are to:

- model the behavior of a vehicle in flight in the framework of rigid body mechanics,

- describe the dynamics of vehicles in the case of flights in and out of the atmosphere (trajectory, eigenmodes, instabilities)

- choose and deploy control and piloting strategies.

It is organized in two steps. First, based on the mechanics course offered in the first year, the mechanics of rigid bodies is introduced to give the necessary tools for the construction of models of aircraft, launchers, satellites, UAVs... For this, two courses will give the basic concepts of flight mechanics and space mechanics. In a second phase, the course will describe the dynamics and control strategies of an aircraft, a satellite and a launcher. These three phases of the course will involve several actors from the aeronautics and space sectors. The sessions will provide an understanding of the models used and the control strategies to be used. The students will take control tools on a specific system and will be able to set up a control strategy in a pre-project phase during the integration teaching.

Challenge Week :

Preamble:

The three integration courses are built in the same way and cover the same learning objectives. The aim is to start from a performance specification for an aircraft, a nanosatellite or a launcher and to make architecture and piloting choices to ensure the expected performance. The common objectives are therefore:

- Understand the constraints of flying systems, and the different levels of modeling of dynamic behavior

- Choose the relevant technical solutions for the control of trajectory, stability and orientation (sensors/actuators...)

- Design a complete system by modeling, including actuators and sensors, actuator sizing, power generation and CPU capacity

- Implementation of an optimal control law, taking into account economic aspects

- Validation of the control law on a realistic model

Challenge week n°1 : Control strategy for a nanosatellite

Associated partner: Thalès Alenia Space via the CentraleSupélec Space Center

Location: Paris-Saclay campus

Brief description: This integration course will be conducted in collaboration with Thalès Alenia Space. The objective is to design a nanosatellite (Cubesat). For a specific mission defined by a specification, participants will propose an orbit, choose the satellite components, design the operating modes and develop a control law.

Challenge week n°2: Definition and design of a launcher mission

Associated partner: CNES Direction des Lanceurs

Location: Paris-Saclay campus

Brief description :

The objective of this integration course is to bring the students, through a space launcher design project, to experience a multi-disciplinary dimensioning loop. To this end, the project is articulated in modules reflecting the unfolding of a design loop, with CNES DLA (Direction des Lanceurs) engineers accompanying the students during each of these modules.

Challenge Week n°3: Aircraft design

Associated partner: Dassault Aviation

Location: Paris-Saclay campus

Brief description:

The objective of this challenge week is to discover the different stages of the design process of a business aircraft, both from a theoretical and a practical point of view. The study will focus on the design of the aircraft and improvement of its performance, the development of a control law, and the risk analysis and certification associated with the developed solution.

2SC5110 – Performance and flight paths

Instructors : **Sihem Tebbani**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **FRENCH**
Type of course : **Specific Course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

The course provides the skills and knowledge needed to model and control flying vehicles (in and out of the atmosphere) to improve system performance. It is divided into two parts.

The first part of this course is a core curriculum whose objectives are to provide a common basis of knowledge and skills. This common core is organized into three parts. First, solid mechanics is introduced to give the necessary tools for the modeling of airplanes, launchers, satellites, UAVs... In a second step, the course describes the dynamics and control strategies of an aircraft. Finally, space mechanics is introduced to give the necessary tools to describe movement, disturbances, and maneuvers of a spacecraft.

The objectives of the second part of the course are to provide new knowledge and skills to reinforce those seen in the core curriculum of this course. It will focus on the design and control of three systems: an aircraft, a launcher, and a satellite. It will provide specific knowledge and skills necessary for the topics of the challenge week.

Numerous experts in aeronautics and aerospace fields are involved in this course.

Quarter number

ST5

Prerequisites (in terms of CS courses)

There is no specific prerequisites.

Syllabus

Core curriculum:

1. **General mechanics :**

This course will provide the basic notions in solid mechanics. It will address the following points:

1. Equation of motion of a rigid body. Fundamental Principles of Dynamics
2. Tutorial 1: Measurement of the parameters of inertia of a mricosatellite.
3. Mechanical linkage between rigid bodies.
4. Tutorial 2: movement of a Cubli.
5. Aerospace actuators (stability of rotation around the main axis of inertia, gyroscopic effect, application to gyroscopic actuators, reaction wheels).
6. TD 3: attitude of a satellite

2. Flight Mechanics :

This part of the course will illustrate the dynamic stability through the stability study of an airplane in flight. The objective is to identify the movements induced by small disturbances around a state of equilibrium and to determine the damping or the amplification of these movements according to

the properties of the aircraft. The lecture part gives all the mathematical modeling tools that will be used in the stabilization study. It will address the following points:

- Definition of Euler angles. Matrix formulation
- Linearized dynamic equations of motion
- Solving linearized equations
- Presentation of the representative modes: phugoid, incidence oscillation, Dutch roll, Roll subsidence mode and spiral divergence.

3. Space mechanics
This course introduces the fundamentals of space mechanics, focusing on the study of free motion in gravity field, orbital manoeuvres and space environmental perturbations. Some insights on inter-planetary missions are given.

Elective course (One course depending on the chosen topic of the challenge week)

In the second part of the course, three courses are proposed, corresponding to an introduction to the projects of the challenge week.

1. Control of an airplane

This course aims to detail the modeling and control of an airplane. It will address the following points:

- Presentation of the specification for the flight performance of an airplane
- Modeling forces acting on the aircraft (including thrust, lift and drag)
- Coefficients and ratio for the study of the trajectory performance.

2. Control of a launcher

The course aims to address the fundamentals of attitude control of a launcher, in both propelled and ballistic phases. The requirements to be met by the control system as well as the physical disturbances to be managed during the flight will be addressed. Command synthesis principles will be presented, as well as aspects relating to the actuators.

3. Control of a satellite
This course aims to detail the modeling and control of a satellite. It will address the following points:

- Architecture of a AOCS
- Typical missions, families of AOCS, types of orbits, disturbing couples,
- Sensors and actuators for a satellite
- control modes and algorithms, contribution of the AOCS
- Specifications for a AOCS system (stability, performance, robustness, different developped controllers).

Class components (lecture, labs, etc.)

Lectures and tutorials.
Several examples of real aircraft and aerospace systems will be presented.
For the general mechanics course, the pedagogy is of the flipped classroom type. Videos will be provided to be studied before the face-to-face session which is a practical application (via a tutorial).

Grading

The specific course will be evaluated individually by a final examination lasting 1 hour 30 minutes. This evaluation will be done by MCQ.

Course support, bibliography

- Orbital Mechanics for Engineering Students, H. D. Curtis, Butterworth-Heinemann. 2013.
- Practical Methods for Aircraft and Rotorcraft Flight Control Design: An Optimization-Based Approach, Mark B. Tischler, Tom Berger, Christina M. Ivler, Mohammadreza H. Mansur, Kenny K. Cheung and Jonathan Y. Soong. ISBN: 978-1-62410-443-5.
- Advances In Aircraft Flight Control, M B Tischler, CRC Press, 28 jun. 1996.
- Aircraft Control and Simulation: Dynamics, Controls Design, and Autonomous Systems Brian L. Stevens, Frank L. Lewis, Eric N. Johnson, John Wiley & Sons, 2 oct. 2015 - 768 pages
- Performance, Stability, Dynamics and Control of Airplanes, Third Edition 2015, Bandu N. Pamadi, ISBN: 978-1-62410-274-5.

Resources

- Teaching team: F. Gatti, E. Bourgeois, Ch. Betrancourt, teachers from CNES, TAS and Dassault Aviation, S. Tebbani (coordinator)
- Maximum of 35 students in each tutorial group.
- Software tools: Matlab

Learning outcomes covered on the course

The objectives are to acquire skills and knowledge to:

- Model the behavior of a flight vehicle in the framework of solid mechanics, flight mechanics, and space mechanics.
- Describe the dynamics of flying vehicles into and out of the atmosphere (trajectory, modes, instabilities).
- Choose and develop control strategies.

This course will also provide a global view of control systems for flying vehicles, as well as performance requirements and associated constraints.

Description of the skills acquired at the end of the course

At the end of the course, students will acquire an operational understanding of the design tools of a flying vehicle in flight through the acquisition of:

- basic concepts in solid mechanics, flight mechanics and space mechanics
- good knowledge of the requirements and constraints of the control of a flying system
- good knowledge of different aerospace systems and vehicles (aircraft, UAV, satellite, launcher).

They will be able to:

- model vehicle dynamics in the case of flights in and out of the atmosphere (trajectory, modes, instabilities).
- Choose and develop control strategies.
- Evaluate the flight performance of the flight of a vehicle and to propose effective and economical solutions to improve it.

More specifically, the aquired skills are:

1. Analyze, design and implement complex systems with scientific, technological, human and economic components (C1).
2. Develop in-depth skills in a scientific or sectoral field and a family of professions (C2).
3. Act, undertake and innovate in a scientific and technological environment (C3).
4. Be operational, responsible, and innovative in the digital world (C6).
5. Know how to convince (C7)

2SC5191 – Control strategy of a nanosatellite

Instructors : **Giorgio Valmorbida**
Department : **DOMINANTE - GRANDS SYSTÈMES EN INTERACTION, DOMINANTE - CONSTRUCTION VILLE TRANSPORTS**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This module is developed in partnership with Thalès Alenia Space. The main goal is to introduce the main tasks on the design of a nanosatellite. For a satellite mission, the participants will propose a satellite orbit, choose sensors and actuators, design the mission modes, propose a dynamical model, design a control laws, simulate the trajectories and assess the resulting performances.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Course "Cubesat design and control: attitude and orbit control systems" of the specific course "performance and flight trajectories".

Syllabus

Traceability matrix : methods for the validation and verification of requirements. Proposal of mission modes, hardware selection. Definition of pointing, mass and power budgets. Disturbance torque assessments. Selection, layout and sizing hardware components.
Dynamics modeling, and simulation including torque disturbances. Writing the technical notice.

Class components (lecture, labs, etc.)

The group will be split into teams of 5 students, which will work independently from the other teams. Each day, a part of the satellite design will be proposed and a document of requirements will be provided. Each team has to deliver either a short report or software, and to give a short talk by the end of the day.

Grading

The evaluation will include a final report, the developed software, and the final oral presentation. At the end of each session, the teams will also present the results of the day, which will be accounted for in the final mark.

Course support, bibliography

Course handouts "Guidage et Pilotage d'un Satellite"

Resources

• Document of requirements in an industrial format
• Orbit simulation software, satellite instrumentation software.
• Supervision by Thalès e Alenia Space engineers and CentraleSupélec Professors

Learning outcomes covered on the course

The main goals are

- Understand aspects and constraints in satellite design, develop models for each design stage and understand the dynamical behavior of the satellite
- Choose a satellite orbit to satisfy the requirements
- Design the hardware by choosing sensors, actuators and energy generators
- Propose a set of operational modes and the control laws to satisfy the performance requirements.

Validate each step of the design with simulation (GMAT, VTS Timeloop, Matlab/Simulink)

At the end of the module, the participants will have completed the main steps in the desing of a AOCS : the choice of the orbit, the choice of harware components and the AOCS architecture as well as the design and validation of control laws.

Description of the skills acquired at the end of the course

1. Analyze, design and implement complex systems made up of scientific, technological, social and economic dimensions. (C1)
2. Acquire and develop broad skills in a scientific or academic field and applied professional areas. (C2)
3. Act, engage, innovate within a scientific and technological environment. (C3).
4. Have a sense of value creation for his company and his customers (C4).
5. Be operational, responsible, and innovative in the digital world (C6).
6. Know how to convince (C7).

2SC5192 – Definition and design of a launcher mission

Instructors : **Sihem Tebbani**
Department : **DOMINANTE - CONSTRUCTION VILLE TRANSPORTS, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In this challenge week, the student will experiment the multidisciplinary sizing and design of a launcher.
It consists in the understanding the interactions between the different technical fields involved in this design.
Another issue is also to understand the associated challenges of each involved technical field and adopt the different sizing methods for a first sizing procedure.
For this propose, the challeng week is organized in several modules of a realistic sizing loop for which students will be supported by CNES DLA engineers.

Quarter number

ST5

Prerequisites (in terms of CS courses)

The course "Guidance and control of a launcher" of the specific course "performance and flight trajectories".

Syllabus

This Challenge Week will be structured around the following modules:

- Mission analysis - launcher staging
- Trajectory
- Liquid propulsion
- Solid Propulsion
- Aerodynamics and mechanical loads
- Sizing of structures
- Launcher control

Each module will be the subject of a dedicated session (half a day per module) during which the students, working in pairs, will design and consolidate a launcher ,meeting specific specifications.

Class components (lecture, labs, etc.)

Engineers from CNES DLA will supervise this Challenge Week.
They will provide a detailed work plan with questions to the students in order to help them to make design choices while ensuring a good understanding of the challenges (technical, programmatic) and the related physical problems.
Analytical and numerical tools should be used by students to address the issues raised.
The hypotheses and data considered should be questioned in order to understand the issues of a multi-disciplinary design loop; these elements will lead students to iterate on their design choices in order to obtain relevant technical solutions.

Grading

The evaluation will include a final report, project progress notes at the end of each module.

Course support, bibliography

1. Detailed workplan structuring the developments to be carried out by the students.
2. Simplified preliminary sizing tools (under WINDOWS 10).

Resources

- Specifications and a workplan of the developments to be carried out by the students.
- Simplified preliminary numerical sizing tools
- Teaching team : engineers of CNES - Direction des Lanceurs.
- Working in pairs.

Learning outcomes covered on the course

At the end of this project, the student will have an operational understanding of the design tools of a launcher via:

- good knowledge of the requirements and constraints for the design of a launcher,
- good knowledge of different systems constituting a launcher,
- understanding the interactions between the different technical disciplines involved in the design of a launcher and the associated challenges.

He will be able to:

- Model the trajectory of a launcher and implement launcher sizing methods,
- Choose and deploy launcher control strategies,
- Evaluate the launcher's flight performance and propose efficient and economical solutions to improve it.
- Know how to meet the requirements of a launcher's multi-disciplinary design.

Description of the skills acquired at the end of the course

- Analyze, design and implement complex systems with scientific, technological, human and economic components (C1).
- Develop in-depth skills in a scientific or sectoral field and a family of professions (C2).
- Act, undertake and innovate in a scientific and technological environment (C3).
- Have a sense of value creation for his company and his customers (C4).
- Be operational, responsible, and innovative in the digital world (C6).
- Know how to convince (C7)

2SC5193 – Aircraft design

Instructors : **Christopher Betrancourt**
Department : **DOMINANTE - CONSTRUCTION VILLE TRANSPORTS, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The goal of this training is to let you discover the different stages of an aircraft design process in both a theoretical and a practical perspective. You will be introduced to the typical methods used in an aircraft design office, and apply this knowledge by doing the preliminary design of your own aircraft After completing this training course, you will have acquired knowledge and skills that will enable you to work out the main aircraft characteristics and layout in a very short time frame.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Have to follow the elective course "Airplane control".

Syllabus

When a team commits to design a new aircraft or to modify an existing aircraft, the project will always follow the same pattern. The process starts by analyzing the market and existing products. Next is the conceptual design which is followed by the preliminary design and detail design before sending the drawings to the workshop which will build a prototype. Obviously, at each stage, several iterations are made as necessary before proceeding to the next stage. In the process, we will begin by a more global or synthetic approach of aircraft design before getting into more and more detail. We will go from a basic concept into full optimization, from using parameters derived from simple statistical data to using sophisticated algorithms.

Grading

Evaluation will take place the last day of the course and include : an oral presentation to present your project and followed by a question and answer session.

Resources

Teacher: industrial partner.

Learning outcomes covered on the course

Student will learn how to:
• Define the layout and configuration of the new aircraft.
• Work out estimates for empty weight and maximum take-off weight.
• Compute wing loading.
• Work out estimates for lift and drag ✧ Work out performance estimates (take-off, climb, cruise, landing).
• Make an analysis of the aircraft's stability and control.
• Compute the applied loads ✧ Select the structural materials.

• Estimate the costs (design, manufacturing, operational).

Of course, the general concepts are not only valid for aircraft design but can equally be applied to the development of any other conceivable product or service.

Description of the skills acquired at the end of the course

1. Analyze, design and implement complex systems with scientific, technological, human and economic components (C1).
2. Develop in-depth skills in a scientific or sectoral field and a family of professions (C2).
3. Act, undertake and innovate in a scientific and technological environment (C3).
4. Have a sense of value creation for his company and his customers (C4).
5. Be operational, responsible, and innovative in the digital world (C6).
6. Know how to convince (C7)

ST5 - 52 - CONTROL OF BIOPROCESSES FOR ENVIRONMENT AND BIOMANUFACTURING

Dominante : VSE (Living-Health-Environment) and GSI (Large Interacting Systems)

Langue d'enseignement : French

Campus où le cours est proposé : Paris-Saclay

Context

Sustainable development plays an increasing important role in the consolidation and evolution of various industrial sectors. Solutions for modernizing and transforming means of production are being studied in order to limit greenhouse gas emissions, in particular by offering alternatives to fossil fuels. Among the solutions studied, this thematic sequence focuses on bioprocesses, which are an alternative, efficient, and environmentally friendly technology.

Bioprocesses are one of the pillars of the transition towards sustainable economy. Their development, based on the use of living systems or their constituents for the production of goods and services, requires the implementation of multidisciplinary knowledge, in particular for the optimization of their functioning, i.e. the maximization of productivity and/or pollutants degradation.

This thematic sequence provides conceptual elements for the development of bioprocesses through the design of automatic systems to deal with different problems:
- Energy production (e.g. biofuels production),
- Pollution treatment (e.g. gas, wastewater and solid waste treatment),
- Greenhouse gas control (e.g. CO_2 capture),
- Production of high added value molecules (e.g. production of drugs, cosmetics).

In this course, the design of bioprocesses is addressed as well as the design of automated systems to maintain the bioprocess under optimal operating conditions in order to maximize their productivity. The approach can be extended to other bioprocess applications not covered here in the biotechnology sector (e.g. stem cell culture for medical applications). The concepts presented can also be applied to broader application sectors, such as pharmaceutical, genetic engineering, cosmetics, agri-food, etc.

The intervention of industrial leaders from the sector allows a better understanding of the issues associated with the use and optimization of bioprocesses in a context of sustainable development.

Necessary prerequisites

Not compulsory but strongly recommended: Thermodynamics, Transport phenomena.

Context and stakes module

This part is organized around half-days of training aimed at presenting the thematic sequence, the integration lessons and introducing the issues associated with bioprocesses in relation to sustainable development. The following activities are proposed:

- Introductory conference on biotechnologies, giving an overview of the evolution of biotechnologies and the current and future needs of this sector.
- Conference on the link between biotechnology and sustainable development.
- Conference on energy applications, providing an overview of energy sources (fossil, nuclear, renewable) and highlighting the interest and role of bioprocesses in the production and storage of energy, as well as the associated challenges.
- Conference on environmental applications, which will take stock of environmental issues (scarcity of resources, pollution, health risks, etc.) and will highlight the interest and role of bioprocesses in the recovery of waste and the conversion of biomass into value-added products.

- Conference on the contribution of bioprocesses for long duration space missions. These bioprocesses are a relevant solution for nutritional autonomy and for recycling water, air, and organic matter in a confined environment. Their control is one of the keys to their reliability, which is necessary given the needs they meet and the isolation in space.
- Conference on control and bioprocesses focusing on the role of automatic control in the design and optimization of bioprocesses for resource recovery.
- Conference on bioethics, showing that the use of bioprocesses raises questions about the ethics of the proposed solutions, especially when these solutions involve the design of organisms whose genome is modified. This conference is an introduction to the questions linked to the use of biotechnologies and, more generally, to the place of Man in the biosphere and the respect of nature and the environment.

Specific course (60 HEE):

Chemical Engineering: Chemical Engineering : application to environment and biomanufacturing ; Génie des procédés : application à l'environnement et aux biofabrications

Brief description: Chemical Engineering consists in designing, operating and optimizing processes for the development of various products and services in many traditional and high-tech sectors (agri-food, biotechnology, cosmetics, fine chemicals, materials, pharmaceuticals, water and waste treatment, etc.) and for the production of traditional, low-carbon, and renewable energies.
This course is an introduction to Process and Bioprocess Engineering and its methodologies. The fundamentals of the course allow students to acquire general tools that can be easily transposed to multiple fields.
The sustainability of processes is a major challenge.
Some processes are intrinsically key tools in the global sustainable development strategy at different scales (local and global), such as the recycling and recovery of many products and the purification of liquid and gaseous effluents. The fact remains that new processes must be developed and existing processes must be optimized (intensification) in order to reduce the impacts of the industrial sector. The challenges associated with this environmental dynamic are multiple: reduction of energy and raw material consumption, costs, waste, risks and dangers.
In addition, bioprocesses have developed very strongly in the last decades for two reasons: (i) the use of living organisms, acting as processing plants, to transform matter, and purify polluted systems (liquid, solid), (ii) the use of biomass to replace fossil resources.
This course is based on concrete examples (simplified in order to make them intelligible), allowing students to apply and learn the fundamentals of the course, while focusing on processes oriented towards sustainable development.
Bioprocesses are studied at the bioreactor scale. The detailed description and understanding of biological phenomena (metabolism, maintenance, etc.) at the cell level are not addressed. The biological agents are thus considered as cellular catalysts transforming raw materials into products according to given kinetic laws whose application does not require any specific background in biology.

Challenge Week (integration courses)

The three integration courses cover the same learning objectives and have a similar structure. The aim is to start from a performance specification for a given bioprocess, to proceed to choices of bioprocess design and control law in order to ensure the expected performances and maximize the productivity of the designed system.

Challenge Week n°1: Optimized biological treatment of urban wastewater

Associated partner: VEOLIA

Location: Paris-Saclay campus

Brief description:

In urban wastewater treatment plants, biological processes are designed to eliminate carbon and nitrogen pollution through the action of microorganisms that develop spontaneously in aerobic or anaerobic environments.

The eliminated pollutants are concentrated in the form of aqueous biomass suspensions or sludge, constituting voluminous waste with fermented target and toxic materials. The treatment of sludge is therefore an important phase of wastewater treatment systems that must ensure the reduction of its volume and odor nuisance. One of

the most common processes for this treatment is anaerobic digestion, which produces liquids with a high concentration of nitrogen that must be treated again. The amount of nitrogen contained in these effluents can represent up to a 20% increase in the nitrogen load to be eliminated by the plant. There are two solutions to this problem: (1) a so-called classical one, in which these concentrated effluents are directly returned to the head of the plant or (2) the anaerobic ammonium oxidation process, or Anammox, an innovative alternative to the traditional nitrification/denitrification processes, allowing the direct transformation of nitrite and ammonium into gaseous nitrogen.

In this challenge week, the objective is to propose control strategies for the two mentioned solutions in order to meet the minimum purification requirements of the treated water and to compare their performance in terms of operating costs and biogas production as a vector for energy recovery from sludge.

Challenge Week n°2: Life support system for space missions

Associated partner: European Space Agency (ESA)

Location: Paris-Saclay campus

Brief description:

ESA is developing a bioregenerative life support system that allows astronauts to live autonomously, without refueling from Earth, during long-duration space missions. This integration teaching concerns the bioprocess that allows regeneration of the habitat atmosphere. It is a photobioreactor implementing microalgae that consume CO_2, produce O_2 and nutrient supplements.

In this week challenge, the objective is to model and size a photobioreactor for 5 astronauts in total autonomy for 1000 days and to ensure the control of the O_2 production via the transfer of light for reasonable performance criteria. These criteria are related to the reliability of operation, safety and risks for the crew, the rate and efficiency of recycling, the activities required for the crew, the energy consumption, the size and mass of the system.

Challenge Week n°3: Advanced supervision of biogas production from waste

Associated partner: BioEnTech

Location: Paris-Saclay campus

Short description:

Anaerobic digestion is a natural process of degradation of organic matter by micro-organisms (bacteria and archaea) in the absence of oxygen (anaerobic conditions). This process allows to recover a fraction of the energy contained in the waste in the form of biogas, a mixture of methane and CO_2. The generalization of these technologies would allow considerable reduction of the energy demand necessary to treat the waste (10% of the energy used on the planet) but could in the long term constitute a source of energy. However, the anaerobic digestion process is complex and involves several hundred species of microorganisms. Moreover, it is unstable, and intermediate compounds (volatile fatty acids) can, under certain conditions, accumulate and lead to the total shutdown of the reactor. To avoid this type of accident, a very precise and costly monitoring is necessary.

In this challenge week, the objective is to propose and develop supervision and control strategies to reduce the risk of reactor acidification and to optimize the production of energy from the waste.

2SC5210 – Chemical Engineering: application to environment and biomanufacturing

Instructors : **Cristian-Felipe Puentes Mancipe**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **FRENCH**
Type of course : **Specific Course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

Chemical Engineering consists in designing, operating, and optimizing processes for the development of various products and services in many traditional and high-tech sectors (agri-food, biotechnology, cosmetics, fine chemicals, materials, pharmaceuticals, water and waste treatment, etc.) and for the production of traditional, low-carbon, and renewable energies.
This course is an introduction to Process and Bioprocess Engineering and its methodologies. The fundamentals of the course allow students to acquire general tools that can be easily transposed to multiple fields.
The sustainability of processes is a major challenge.
Some processes are intrinsically key tools in the global sustainable development strategy at different scales (local and global), such as the recycling and recovery of many products and the purification of liquid and gaseous effluents.
The fact remains that new processes must be developed and existing processes must be optimized (intensification) in order to reduce the impacts of the industrial sector. The challenges associated with this environmental dynamic are multiple: reduction of energy and raw material consumption, costs, waste, risks, and dangers.
In addition, bioprocesses have developed very strongly in the last decades for two reasons: (i) the use of living organisms, acting as processing plants, to transform matter, and purify polluted systems (liquid, solid), (ii) the use of biomass to replace fossil resources.
This course is based on concrete examples (simplified in order to make them intelligible), allowing students to apply and learn the fundamentals of the course while focusing on processes oriented toward sustainable development.
Bioprocesses are studied at the bioreactor scale. The detailed description and understanding of biological phenomena (metabolism, maintenance, etc.) at the cell level are not addressed. The biological agents are thus considered as cellular catalysts transforming raw materials into products according to given kinetic laws whose application does not require any specific background in biology.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Not compulsory but strongly recommended: Thermodynamics, Transport phenomena.
The case studies conducted involve biochemical or chemical reactions. However, no prior knowledge of chemistry or biology is required.

Syllabus

1. Introduction to chemical engineering; material balance
Case study: Process for the production of bioethanol (conversion of renewable raw materials by industrial biotechnology)
2. Ideal reactor models (perfectly stirred and plug flow)
Case study: Design of biological treatment basins of an urban wastewater treatment plant (environmental

bioprocess)
3. Thermal energy balances
Case study: Design of a bioreactor for baker's yeast production in batch mode (biomass production by industrial biotechnology)
4. Liquid-vapor equilibria, flash distillation
Application exercise: Flash distillation of ethanol-water mixture (purification of biofuel, alternative to fossil fuels)
5. Multi-stage distillation
Case study: Multi-stage distillation of bioethanol (purification of biofuel, alternative to fossil fuels)
6. Mass transfer: Diffusion and Convection
Case study: Raceway production of Spirulina microalgae (production of nutrients for food and feed by industrial biotechnology)
7. Mass transfer: Permanent Contact Technologies
Case study: treatment of a gaseous effluent with pollutant removal (environmental process)
8. Intermediate group exam
Case study: modeling and simulation of a bioprocess for polymer production (production of added value molecules by industrial biotechnology)

Class components (lecture, labs, etc.)

The course module is organized in lectures (10,5 h), to introduce knowledge and methodological tools, which will be then applied through case studies (10,5 h).

Grading

- Intermediate group exam: Solution of a case study of modeling and simulation of a bioprocess. Written report including the computer code and results analysis (40 % of the grade).
- Individual final written exam: 1.5-hour case study (60 % of the grade).

Course support, bibliography

• **Slideshows**

• Techniques de l'ingénieur :
+ Charpentier J., Génie des procédés, développement durable et innovation – Enjeux et perspectives, 2013
+ Moulin J.P., Pareau D., Rakib M., Stambouli M., Transfert de matière – Méthodologie, 2000
+ Moulin J.P., Pareau D., Rakib M., Stambouli M., Isambert A., Transfert de matière – Distillation compartimentée idéale, 2001
+ Moulin J.P., Pareau D., Rakib M., Stambouli M., Transfert de matière – Autres opérations compartimentées, 2002
+ Buch A., Rakib M., Stambouli M., Transfert de matière- Cinétique du transfert de matière entre deux phases, 2008
+ Sun L.M., Thonnelier J.Y., Perméation gazeuse, 2004
+ Vuillermaux J., Réacteurs chimiques – Principes, 1994
+ Boulinguiez B., Le Cloirec P., Purification de biogaz – Élimination des COV et des siloxanes, 2011

• **General Books:** Perry Chemical Engineer's Handbook, 8th edition, 2007, McGraw-Hill, New York

• **Specific books:**
- *Reactor and bioreactor engineering*
+ Coulson and Richardson’s Chemical Engineering – Volume 3A: Chemical and Biochemical Reactors and Reaction Engineering, 4th Edition, 2017, Elsevier. Oxford
+ Fogler H.S., Elements of chemical reaction engineering, 5th Edition, 2016, Pearson Education, Englewood Cliffs
+ Levenspiel O., Chemical Reaction Engineering, 3rd edition, 1999, John Wiley and Sons, New York
+ Villadsen J., Nielsen J., Lidén G., Bioreaction Engineering Principles, 3rd Edition, 2011, Springer, New York
- *Heat and mass transfer*
+ Bergman T.L., Lavine A.S., Incropera F.P., Dewitt F., Fundamentals of Heat and Mass Transfer, 7th Edition, 2011, John Wiley and Sons, New York
+ Coulson and Richardson’s Chemical Engineering – Volume 1B: Heat and Mass Transfer: Fundamentals and Application, 7th Edition, 2018, Elsevier, Oxford
+ Cussler E.L., Diffusion Mass Transfer in Fluid systems, 3rd Edition, 2009, Cambridge University Press, Cambridge
+ Treybal R., Mass Transfer Operations, 4th Edition, 1982, McGraw Hill, New York
- *Bioethanol production*

+ Cardona C.A., Sanchez O.J., Gutierrez L.F, Process synthesis for fuel ethanol production, 2010, CRC Press, Boca Raton
+ Naik S.N., Goud V.V., Rout P.K., Dalai A.K, Production of first and second generation biofuels: A comprehensive review, Renewable and Sustainable Energy Reviews 14, 2010, 578–597
+ Vohra M., Manwar J., Manmode R., Padgilwar S., Patil S. Bioethanol production: Feedstock and current technologies, Journal of Environmental Chemical Engineering 2, 2014, 573–584

Resources

- Teaching staff: Irma LIASCUKIENE, Victor POZZOBON, François PUEL, Cristian PUENTES,
- Maximum enrolment in tutorials: 30 to 35 students
- Software, number of licenses required: Excel, Python, MATLAB

Learning outcomes covered on the course

At the end of this course, students will be able to:
• List the type of mass transfer mechanisms and its coupling to heat transfer,
• Identify the different mass transfer mechanisms (diffusion / convection) operating in a given configuration and the potential coupling between heat and mass transfer,
• Write mass balances, taking into account, if necessary, chemical or biochemical reaction kinetics,
• Simplify a seemingly complicated problem, where several transfer phenomena coexist, by taking into account only the main ones,
• Formalize phenomena into equations through elemental balances,
• Size chemical/biochemical conversion and separation technologies based on thermodynamic and kinetic considerations.

Description of the skills acquired at the end of the course

- C1.1 : analyze: study a system as a whole. Identify, formulate and analyze a system within the framework of a transdisciplinary approach with its scientific, economic and human dimensions, etc. Milestone 2.
- C1.2. Modeling: using and developing the appropriate models, choosing the correct modeling scale and the relevant simplifying assumptions. Milestone 2.
- C1.3. Solve: solve a problem with a practice of approximation, simulation, and experimentation. Milestone 1.

2SC5291 – Optimized biological treatment of urban wastewater

Instructors : **Cristian-Felipe Puentes Mancipe**
Department : **DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In urban wastewater treatment plants, biological processes are designed to eliminate carbon and nitrogen pollution through the action of microorganisms that grow spontaneously in aerobic or anaerobic environments. The pollutants removed are concentrated in the form of aqueous suspensions or sludge, which constitutes bulky waste containing fermentable and toxic materials. The sludge management is therefore an important phase of treatment systems aiming to ensure the reduction of their volume and odour nuisance. One of the processes used for this treatment is anaerobic digestion, which produces liquids with a high concentration of nitrogen that must be re-treated. The amount of nitrogen contained in these effluents can represent up to 20% increase in the nitrogen load to be eliminated by the plant. There are two solutions to address this problem: (1) a so-called classical one, in which these concentrated effluents are directly returned to the primary plant, or (2) the anaerobic ammonium oxidation process, or Anammox, an innovative alternative to traditional nitrification/denitrification processes, allowing the direct transformation of nitrite and ammonium into gaseous dinitrogen.

The objective of this ‘challenge week’ is to develop control strategies for the two solutions mentioned in order to meet the minimum treatment requirements of the treated water and to compare their performance in terms of operating costs and biogas production as a vector for sludge energy recovery.

Quarter number

ST5

Prerequisites (in terms of CS courses)

There are no specific prerequisites.

Syllabus

- Introduction on pollution, water and sludge treatment technologies.
- Presentation on the modeling of water treatment plants: focus on the formulation of the activated sludge reactor model and the moving-bed reactor (MBBR).
- Simulation of the classical process with constant and variable feed flow. Understanding of unit processes, impact of operating parameters on effluent composition, dynamics of microbial populations.
- Simulation of the Anammox process with constant and variable feed flow. Understanding of the functioning of unitary processes, impact of operating parameters on the composition of the effluent, dynamics of microbial populations.
- Proposal of PID regulation strategy in order to respect the imposed depollution specifications. Adjustment of the PID controller parameters by an empirical method of trial and error calibration. Evaluation of the quality of the controllers (static error, response time, overshoot, disturbance absorption).
- Comparison of the two processes on the basis of operating costs (additional carbon input and electricity consumption for aeration needs), sludge production and biogas production by anaerobic digestion.

Class components (lecture, labs, etc.)

The teaching team and the industrial partner will carry out a first session to introduce the problem. A presentation on the modeling approach of water treatment plants will be proposed with a focus on biological treatment reactors. Then, the students will be divided into teams. All the teams will work on the same specifications, so that they can deal with both process engineering and control aspects of the teaching.
Scientific articles and technical documentation will be provided for further study of the concepts covered. A written procedure for the empirical adjustment of PID parameters in the simulation software will also be provided.
Finally, each team will propose a control strategy to the partner, which will include the comparison and critical analysis of the two processes.

Grading

The evaluation is based on: continuous assessment, a written report, an oral evaluation.

Course support, bibliography

PDF support from the industrial partner

Reference books on control of bioreactors:
– Bastin G., Dochain D., On-line Estimation and Adaptive Control of Bioreactors, Elsevier, 1990.
– D. Dochain (éditeur). Automatic Control of Bioprocesses, Wiley-ISTE, 2008.

Documentation from Techniques de l'ingénieur:

– BOEGLIN J.C., Traitement biologique des eaux résiduaires, Techniques de l'Ingénieur, J3942 V1, Décembre 1998.
– BOEGLIN J.C., Traitements et dispositions finales de boues résiduaires, Techniques de l'Ingénieur, J3944 V1, Septembre 2000.
– GAÏD A., Traitement des eaux résiduaires, Techniques de l'Ingénieur, C5220 V1, Février 2008.

– SPERANDIO M., HERAN M., GUILLOT S., Modélisation biologique des procédés biologiques de traitement des eaux, Techniques de l'Ingénieur, W6500 V1, Août 2007.

Papers on Anammox process:
– NSENGA KUMWIMBA M., LOTTI T., SENEL E., LI X., SUANON F. Anammox-based processes: How far have we come and what work remains? A review by bibliometric analysis, Chemosphere 238 (2020) 1-17.
– VAN DER STAR W.R.L., ABMA W.R., BLOMMERS D., MULDER J.W., TOKUTOMI T., STROUS M., PICIOREANU C., VAN LOOSDRECHT M.C.M., Startup of reactor for anoxic ammonium oxidation: Experiences from the first full-scale anammox reactor in Rotterdam, Water Research 41 (2007) 4149– 4163.
– TAO C., HAMOUDA M.A., Steady-state modeling and evaluation of partial nitrification-anammox (PNA) for moving bed biofilm reactor and integrated fixed-film activated sludge processes treating municipal wastewater, Journal of Water Process Engineering 31 (2019) 1-9.
– LACKNER S., GILBERT E.M., VLAEMINCK S.E., JOSS A., HORN H., VAN LOOSDRECHT M.C.M., Full-scale partial nitritation/anammox experiences – An application survey, Water Research 55 (2014) 292-303.
– BIASE A., KOWALSKI M.S., DEVLIN T.R., OLESZKIEWICZ J.A., Moving bed biofilm reactor technology in municipal wastewater treatment: A review, Journal of Environmental Management 247 (2019) 849–866.
– VEUILLET F., LACROIX S., BAUSSERON A., GONIDEC E., OCHOA J., CHRISTENSSON M., LEMAIRE R. Integrated fixed-film activated sludge ANITATMMox process – a new perspective for advanced nitrogen removal, Water Science and Technology 69.5 (2014), 915-922.

Resources
– Software tools: SUMO, Complete simulator of the classical treatment plants
– Documentation describing the unitary treatment processes (wastewater and sludge)
– Supervision:

o Teaching staff: Cristian Puentes (associate professor, CS, LGPM), Sette Diop (researcher, L2S), Nicolas Brunet (PhD student, CS, LGPM)
o Industrial partner

Learning outcomes covered on the course

At the end of the Challenge Week, the student will be able to:
– Simulate an urban wastewater treatment plant with treatment of secondary effluents or sludge.
– Understand the operation of the Anammox process as an alternative to the traditional treatment of nitrogen pollution.
– Design PID control loops to maintain the system at desired operating conditions (regulatory requirements on nitrogen and carbon concentration).
– Determine and critically analyze the best solution for the treatment of effluents with high ammonia concentration in terms of operating costs and sludge energy recovery.

Description of the skills acquired at the end of the course

– C1.1, Analyze: study a system as a whole, the situation as a whole. Identify, formulate and analyze a system within a transdisciplinary approach with its scientific, economic, human dimensions, etc. Milestone 1
– C1.2, Modeling: using and developing the appropriate models, choosing the correct modeling scale and the relevant simplifying assumptions. Milestone 2
– C2.3, Identify and independently acquire new knowledge and skills. Milestone 2
– C4.2, Propose one or more solutions answering the question rephrased in terms of value creation and complemented by the impact on other stakeholders and by taking into account other dimensions. Quantify the value created by these solutions. Arbitrate between possible solutions. Milestone 1
– C7.1, Basically: Structure ideas and arguments, be synthetic (assumptions, objectives, expected results, approach, and value created). Milestone 2
– C7.2, On the relationship with others: Understand the needs and expectations of his interlocutors evolutionarily. Encourage interactions, be a teacher, and create a climate of trust. Milestone 2

2SC5292 – Life support system for space missions

Instructors : **Hervé Duval**
Department : **DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

L'enseignement Système de support de vie pour le spatial est l'un des 3 Enseignements d'Intégration (EI) qui concluent la Séquence Thématique n°5 (ST5) Commande de bioprocédés pour l'environnement et les biofabrications.

L'Agence spatiale Européenne (ESA) développe un système de support de vie biorégénératif permettant aux astronautes de vivre de façon autonome, sans ravitaillement de la Terre, lors de missions spatiales de longue durée. Cet enseignement d'intégration porte sur le bioprocédé qui permet de régénérer l'atmosphère de l'habitacle. Il s'agit d'un photobioréacteur mettant en œuvre des microalgues qui consomment le CO2, produisent O2 et des compléments nutritifs.
L'objectif est de modéliser et dimensionner le photobioréacteur pour 5 astronautes en autonomie totale pendant 1000 jours, assurer le contrôle de la production en O2 via le transfert de lumière pour des critères ALiSSE raisonnables (en lien avec la fiabilité de fonctionnement, la sécurité et les risques pour l'équipage, le taux et l'efficacité du recyclage, les activités requises pour l'équipage, la consommation d'énergie, l'encombrement et la masse du système).

Quarter number

ST5

Prerequisites (in terms of CS courses)

There are no specific prerequisites.

Syllabus

- Suivi de culture de microalgues et caractérisation de la cinétique de croissance
- Pré-dimensionnement du photobioréacteur
- Modélisation multi-physique du photobioréacteur
- Implémentation du modèle sur Simulink
- Implémentation du couplage physique entre le photobioréacteur et l'habitacle
- Stratégie de commande du photobioréacteur
- Implémentation de régulation sur Simulink
- Tests de robustesse
- Optimisation du dimensionnement et de la régulation

Class components (lecture, labs, etc.)

This training course is dedicated to Problem solving. Students will confront the multiphysics aspects of bioprocesses. They will apply the concepts introduced in the chemical engineering course of the ST5 and in the control theory course of the common core.
The course is scheduled over 5 consecutive days. It begins with a half-day project launch. During the week, the students work in groups of 4 and are supervised by a team of teachers from LGPM and L2S laboratories. Each

group addresses the different aspects of the modelling approach and confront reality through a cell culture training.
Updates will be held daily: sharing of information, methodological input, additional courses. The training course ends with a debriefing session in front of ESA Engineers.

Grading

The final mark depends on: individual assiduity, group involvement, relevance of the multiphysics model, control strategy of the bioreactor, final design of the bioreactor, presentation, report.

Course support, bibliography

Presentation slides, scientific and technical articles will be provided during the course.

Resources

Teaching staff: H. Duval (Professor, CS, Département MEP, LGPM) S. Tebbani (Professor, CS, Département MEP, L2S), B. Taidi (Professor, CS, Département MEP, LGPM).
Maximum enrolment: 30
Software, number of licenses required: Matlab Simulink (30)
Equipment, specific classrooms (department and room capacity): biology preparation room (LGPM)

Learning outcomes covered on the course

At the end of the course, the students will be able to:
1. size a bioreactor;
2. establish a multiphysics model by aggregating knowledge from different
scientific fields (biology, transport phenomena, biochemical engineering);
3. propose a relevant control strategy;
5. keep a critical eye on a model and test its robustness.
6. perform cultivation to estimate the proliferation kinetics of a microorganism strain;
7. provide a comprehensive presentation of a complete control strategy combining modeling, estimation, and control strategies.

Description of the skills acquired at the end of the course

C1. Analyse, design, and implement complex systems made-up of scientific, technological, social, and economic dimensions
C2. Acquire and develop broad skills in a scientific or academic field and applied professional areas
C4. Create value for for companies and clients
C6. Advance and innovate in the digital world
C7. Strengthen the Art of Persuasion

2SC5293 – Advanced supervision of biogas production from waste

Instructors : **Julien Colin**
Department : **DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Anaerobic digestion is a natural process of degradation of organic substances by micro-organisms (bacteria and archaea) in the absence of oxygen (anaerobic conditions).
This process makes it possible to recover a fraction of the energy contained in the waste in the form of biogas, a mixture of methane and CO2.
The widespread use of these technologies would on the one hand considerably reduce the energy demand necessary to treat waste (10% of the energy used on the planet) but could in the long term constitute a source of energy.

However, the anaerobic digestion process is complex and involves several hundred species of microorganisms. Moreover, it is unstable, and intermediate compounds (volatile fatty acids) can, under certain conditions, accumulate and lead to the total shutdown of the reactor. To avoid this, very precise and costly monitoring is necessary.

The objective of the Challenge Week is to propose and develop monitoring and control strategies to reduce the risk of reactor acidification and to optimize energy production from waste.

Quarter number

ST5

Prerequisites (in terms of CS courses)

There are no specific prerequisites.

Syllabus

Students will first need to understand an anaerobic digestion model that will be provided and simulate it for different conditions.
In particular, they will need to simulate reactor acidification under conditions of overloading the reactor.
They must propose a simulator with a simplified model for this complex system, for the purpose of implementing control and estimation strategies.
In a second step, they will have to develop observers to evaluate certain intermediate compounds, and in particular volatile fatty acids. It is desirable that a self-calibration dynamic is introduced to take into account the slow drifts of certain model parameters.
Other groups will use the models to develop control strategies. Different approaches will be implemented (e.g. PID, feedback control).
In the end, a supervisor will be proposed by associating an observer(s) to a control law. The performances of the different supervisors will be compared for different reactor operating scenarios.

Class components (lecture, labs, etc.)

Students will be divided into groups. The project will be carried out by organizing the internal work of each group in order to address the different themes of the specifications.
Analytical and numerical tools will have to be developed by the students in order to address the problems raised. The hypotheses and data considered must be questioned; these elements will lead the students to iterate on their design choices in order to obtain relevant solutions.

Grading

The evaluation will include a continuous assessent, a final report, and an oral presentation.

Course support, bibliography

- Anaerobic Digestion Model No. 1, IWA Publishing, 2002.
- Dynamical Model Development and Parameter identification for an anaerobic wastewater treatment process, O. Bernard et al., *Biotechnology and bioengineering*, *75*(4), 424–438, 2001.
- Nonlinear adaptive control for bioreactors with unknown kinetics, L. Mailleret, O. Bernard, and J.-P. Steyer, Automatica, 40(8), 1379–1385, 2004.
- On-line Estimation and Adaptive Control of Bioreactors, G. Bastin, D. Dochain, Elsevier, 1990.
- Automatic Control of Bioprocesses, éditeur D. Dochain. Wiley-ISTE, 2008.

Resources

1. Simulator of the bioprocess to be studied,
2. State-of-the-art and a description of the studied bioprocess.

- Supervision: researchers from INRIA (Sophia-Antipolis), teacher-reseacrhers of CentraleSupélec, with regular contact with the industrial partner.
- Work in group.

Learning outcomes covered on the course

At the end of the Challenge Week, the students will be able to:

- Model a bioprocess for the culture of a microorganism for environmental application
- Design software sensors to reconstruct variables not available online
- Design control laws to maintain the system at desired operating conditions (pH, temperature, concentrations, etc.) to maximize the productivity of the bioprocess.
- Analyse the proposed solution (including economic analysis and ecological footprint) and be critical of the results obtained.

Description of the skills acquired at the end of the course

– C1.1, Analyze: study a system as a whole, the situation as a whole. Identify, formulate and analyze a system within a transdisciplinary approach with its scientific, economic, human dimensions, etc. Milestone 1
– C1.2, Modeling: using and developing the appropriate models, choosing the correct modeling scale and the relevant simplifying assumptions. Milestone 2
– C2.3, Identify and independently acquire new knowledge and skills. Milestone 2
– C4.2, Propose one or more solutions answering the question rephrased in terms of value creation and complemented by the impact on other stakeholders and by taking into account other dimensions. Quantify the value created by these solutions. Arbitrate between possible solutions. Milestone 1
– C7.1, Basically: Structure ideas and arguments, be synthetic (assumptions, objectives, expected results, approach, and value created). Milestone 2
– C7.2, On the relationship with others: Understand the needs and expectations of his interlocutors evolutionarily. Encourage interactions, be a teacher, and create a climate of trust. Milestone 2

ST5 - 53 - AUTONOMOUS AND CONNECTED VEHICLE

Dominante : SCOC (Communicating Systems and Connected Objects)

Langue d'enseignement : French

Campus où le cours est proposé : Paris-Saclay

Engineering problem

Today's vehicles are equipped with a multitude of sensors and electronic processing that provide driving assistance and even a certain level of autonomy in well-defined contexts. Today's vehicles are also connected to provide information on traffic conditions and navigation. According to roadmaps in the field, by 2030, the vehicle should be subject to complete connectivity via intelligent communication systems and adapted technologies to enable total autonomy, reducing the driver to a simple passenger who will only have to indicate his destination before departure. But before we get there, engineers will have to help answer many questions, of which we can give a taste. First of all, on a technical level, will technology be able to completely replace the driver? Or how can such systems be designed and validated while guaranteeing reliability and safety? From an ethical and regulatory point of view, how can personal data be protected, knowing that the vehicle will be connected to a network at all times and therefore likely to communicate information outside the cabin? From an economic point of view, upheavals are to be expected in the value chain of the automotive sector with the rise of the GAFAMs in this field and the future management of vehicle systems by operators. On the societal level, what new services could emerge? Finally, from an environmental point of view, how can we ensure that the autonomous and connected vehicle minimizes our ecological footprint?
During this thematic sequence, students will be trained in functional modeling methods, a preliminary step in any complex system design, and in control techniques. A specific course on the issue will provide an overview of technologies used in this context such as digital methods of modeling, simulation and validation vehicles, electronic architectures embedded, processing of multi-sensor data fusion, artificial intelligence for the vehicle, and communication protocols V2V and V2X. During the integration course, students will have to put into perspective all the knowledge acquired, starting from a specification and going up to the validation on a physical platform, constituted here by a system of rolling robots.

Adviced prerequisites

It is advisable to have taken the SPI Electronic Systems course and the SPI Networks and Security course.

Context and issue modules:

This part is structured in conferences and round tables allowing to apprehend the problematic, the technologies and the stakes related to the autonomous and connected vehicle, namely the associated societal stakes such as safety, environment, traffic fluidity, the social-economic and industrial stakes.

Specific course (60 HEE) : Architecture and technology of the autonomous vehicle

Brief description:

The first part of the course focuses on the definition of an autonomous vehicle mobility system and in particular its functional architecture (perception, processing, communication, actuation, but also propulsion and energy conversion) as well as the development and validation methods of autonomous driving systems or driver assistance systems (AD/ADAS). The course then focuses on the electrical and electronic architecture of the vehicle (power supply network, computers, communication bus and embedded sensors). It is also a question of understanding the physical and environmental constraints to which the on-board electronics are subjected, to apprehend the problems

of operating safety and real-time processing crucial in the automotive field. Some of these concepts are addressed and deepened through a workshop-type session in small groups around a case study of a level 4 autonomous vehicle. Also, a practical session allows to implement a real time embedded image processing with automatic code generation tools on electronic boards.

A second part addresses the processing and algorithms implemented for the autonomous vehicle. Control laws specific to the autonomous vehicle are addressed (Linear Quadratic Regulator, Kalman filtering, neural networks, fuzzy logic...) as well as artificial intelligence (AI) techniques relevant to the autonomous vehicle (supervised learning, connectionist AI). On this processing part, a practical session allows to study and test a control law for automatic parking, another one aims at studying the basic techniques of image processing and a third one studies deep learning algorithms in an automotive context.

A third part focuses on vehicular communication technologies with a comparison of existing communication means. The evaluation of the performance of a vehicular communication network will be addressed and this includes a study of the link budget for coverage as well as an analysis of the different channel access mechanisms (Aloha, Slotted-Aloha and CSMA/CA). A practical session allows the simulation and practical application of the concepts seen in this part.

Challenge week : Design of a "last mile" urban delivery system using autonomous and connected vehicles

Associated partner: Renault, Mathworks

Location: Paris-Saclay campus

Short description :

The challenges of autonomous and connected vehicles do not only concern the automotive sector. The integration course proposed here will enable you to understand the design approach of a complex and critical system, and the plurality of issues of the autonomous and connected vehicle, through an industrial scenario in an appropriate context. The scenario chosen is that of a so-called "last mile" delivery, specified below.

The cost and delivery time of a parcel by carrier is strongly impacted by the last mile, especially in urban areas. Because of traffic jams and parking, delivery trucks could advantageously be replaced at the entrance to large cities by lighter means of transport adapted to the urban environment.

The use of bicycles is proving to be too costly; in the short term, transporters are considering a fully automated last-mile delivery. The solution consists of managing a fleet of autonomous and connected robots that carry out delivery routes based on arrivals, delivery addresses and the robots' characteristics.

Delivery trucks drop off the robots at the entrance of city centers. Each robot is in charge of one or more parcels and has a route to follow to deliver all the parcels as quickly and efficiently as possible. In addition to being able to move efficiently in an urban environment while avoiding obstacles, pedestrians and other vehicles, the robots must communicate with each other (V2V) and with the infrastructure (V2I) in order to avoid, for example, congestion points (demonstrations, work zones, etc.) and to have their route re-planned in real time.

You will work in a team in charge of designing such a delivery system. You will follow a model-driven system engineering approach to specify the system's functionalities. You will adopt a modeling methodology to develop the necessary algorithms (control/command, sensor fusion, data fusion, decision making and telecommunications) to meet the specifications. A small-scale test platform will allow you to evaluate the quality of the resulting delivery system and refine the algorithms.

During this work, you will have to take different points of view: system by establishing the control/command and communication strategy between vehicles; functions through the algorithms; components through your choices of implementation of these algorithms in order to take into account the specific constraints of the application (latency, limited resources, etc.)

2SC5310 – Architecture and technology of the autonomous vehicle

Instructors : **Caroline Lelandais Perrault**
Department : **DÉPARTEMENT ÉLECTRONIQUE ET ÉLECTROMAGNÉTISME**
Language of instruction : **FRENCH**
Type of course : **Specific Course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

The objective of this course is to familiarize students with the architectures and technologies used for the autonomous and connected vehicle (ACV) and their means of development.
To do this, it is necessary to define what is a mobility system in which the vehicle is embedded and then to understand the functional architecture of the ACV. As the functions of the ACV are essentially composed of electrical and electronic systems, the electrical and electronic hardware architecture is presented as well as its specificities and constraints due to the environment in which the automobile operates. Also at the hardware level, intelligent sensors and real-time embedded aspects of processing are studied. At the processing level, traditional or more advanced control laws, image processing and artificial intelligence are discussed. At the communication level, the "vehicle-to-vehicle/vehicle-to-infrastructure" (V2X) technologies, the associated protocols, the characteristics and constraints of the communication channels for the application are studied. Finally, at the level of vehicle validation, the development process as it is carried out by manufacturers is presented.

Quarter number

ST5

Prerequisites (in terms of CS courses)

To follow this thematic sequence, it is recommended to have taken one of the SPI courses in Electronic Systems (two occurrences in SG1 and two occurrences in SG3) and one of the SPI courses in Networks and Security (one occurrence in SG1 and two occurrences in SG3). The Modeling course given in ST2 is also a prerequisite.

Syllabus

I Mobility system and embedded electronics
· Definition of the mobility system (infrastructure/vehicle) and architecture of the autonomous and connected vehicle (perception, processing, communication, actuation, and propulsion and energy conversion)
· AD/ADAS development process
· The electrical and electronic architecture of the vehicle (power supply network, ECUs, communications bus)
· Hardware specificities in automotive electronics (physico-chemical environment, EMC, reliability, card manufacturing process, operating safety)
II On-board algorithms and processing
· Image processing
. Embedded development on boards
. Control laws for the autonomous vehicle (LQR, Kalman filtering, neural networks, fuzzy logic...)
· Artificial intelligence for autonomous vehicles
III Communication of the vehicle with its environment
· V2X Technologies
· Channel access, traffic, and performance
Note: this outline does not reflect precisely the chronology of the course

Class components (lecture, labs, etc.)

This course is made up of half lectures and half practical work

Grading

The final exam for the specific course will be a 1.5 hour written exam and assess skills C1 and C6. Some practical work will also be evaluated and contribute to the evaluation of skill C6.

Resources

The courses will be taught by CentraleSupélec professors and by industrial experts from automotive manufacturer or automotive electronics companies.

Learning outcomes covered on the course

At the end of this course, students will be able to understand the electrical and electronic architecture of an autonomous and connected vehicle, the physical constraints that the vehicle must face, the communication technologies between the vehicle and its environment, and the methodology for developing such systems. They will be able to model and simulate functions of the autonomous and connected vehicle in a simplified context, particularly at the level of perception, control, and communication functions. They will be able to implement and test a detection algorithm on a physical system of electronic cards.

Description of the skills acquired at the end of the course

C1 : Analyze, design and build complex systems with scientific, technological, human and economic components
C6 : Be operational, responsible and innovative in the digital world

2SC5390 – Design of a "last mile" urban delivery system using autonomous and connected vehicles

Instructors : **Morgan Roger**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The challenges of autonomous and connected vehicles do not only concern the automotive sector. The integration teaching offered here allows you to understand on the one hand the approach of designing a complex and critical system, and on the other hand the plurality of problems of the autonomous and connected vehicle, through an industrial scenario in an adapted context.

The chosen scenario is that of a so-called "last mile" delivery. The cost and delivery time of a parcel by carrier is strongly impacted by the last mile, especially in urban areas. Due to traffic jams and parking, delivery trucks could advantageously be picked up at the entrance to major cities by lighter means of transport adapted to the urban environment. Using bikes is too expensive; the carriers consider in the short term a fully automated delivery on the last mile. The solution consists in managing a fleet of autonomous and connected robots carrying out deliveries, based on arrival times, delivery addresses and characteristics of the robots.

You work in a team in charge of designing such a delivery system. In this context, you follow a model-oriented system engineering process to specify the functionality of the system. You adopt a modeling methodology to develop the necessary algorithms (control / command, sensor fusion, data fusion, decision making and telecommunications) to meet the specifications. A reduced-scale test platform allows you to assess the quality of the delivery system obtained and improve the algorithms.

Quarter number

ST5

Prerequisites (in terms of CS courses)

1st-year SPI module "Electronic systems"
1st-year SPI module "Network security"
Specific teaching module "Architecture and technologies for smart and connected vehicules"

Syllabus

The following technical aspects are implemented in this integration teaching:

- functional needs analysis, system specifications
- system modeling
- state machines
- control law
- telecommunications
- communications protocol
- image processing
- sensor fusion

- embedded and real-time processing
- mixed hardware-software computation

Class components (lecture, labs, etc.)

The objective is to complete a technical proof of concept on a reduced-scale platform made up of robots running on an adapted support schematically representing the urban environment. Teams of 5 or 6 students are formed beforehand so as to present a broad spectrum of skills. After an initial functional analysis of the system based on brainstorming, the teams decide on their internal organization in order to deal with the various aspects in parallel and with consistency: hardware, modeling, embedded intelligence, connectivity. Each team is given a robot and can access the test rooms to validate the behavior of the system in a physical environment and refine its functionality. The last day of the week is devoted to the preparation of the evaluation and to the evaluation itself.

Grading

The grading is done through regular progress reports with the supervision team during the week (once per half-day), as well as with a final evaluation at the end of the week, comprising an oral presentation describing the design choices and the innovations of the system, and demonstrations of its performances both in simulation and in real-life settings on the test platform, in front of a panel of teachers and industrial experts.
It is based on the following criteria: technical knowledge, compliance of results to expectations, quality of communication, originality of the work, and contentiousness of the work.

Resources

Human resources: a team of teachers specializing in the various engineering fields concerned (electronics, telecommunications, modeling, signal processing) present 100% of the time; automotive (Renault) and modeling (Mathworks) industrial experts visiting during the week and present for the evaluation.
Logistical resources: work rooms for student teams, large rooms for test and evaluation platforms, a teachers' HQ.
Material resources: wheeled robots (including 4 driving wheels, an Arduino board, a Raspberry Pi nanocomputer, a camera and several other on-board sensors, batteries).
Software resources: Matlab / Simulink, Linux, Python, C ++, OpenCV, ...

Description of the skills acquired at the end of the course

The following skills will be evaluated during this learning activity: C2, C4 and C7. The skills assessment will be based on the regular progress reports with the supervision team (once per half-day), on the demonstrated performances of the system, and on the final oral presentation.

ST5 - 54 - THE ECO-NEIGHBORHOOD, A COMPLEX SYSTEM. SUSTAINABLE DEVELOPMENT & COMPLEX PROJECT MANGEMENT

Dominante : CVT (Construction, City, Transportation) and GSI (Large Interacting Systems)

Langue d'enseignement : French

Campus où le cours est proposé : Paris-Saclay

Engineering problem:

The eco-neighborhood is an interesting case of a complex system. It requires a multidisciplinary approach combining real estate and construction, mobility (flows and infrastructures), urban networks and the problems of consumption of natural resources (water, energy, waste) but also geography, sociology and the history of places and people. It involves implementation at various scales, from the political decisions required for its emergence and implementation, to the geographical location of the territory, to the choice of heating and lighting methods for each home.

The development market is undergoing a major transformation, with public developers ceding ground to private developers who are emerging among the various real estate developers.

The engineering problematic of this thematic sequence is therefore the following: how to approach all the studies necessary to the creation of an eco-neighborhood in order to make a coherent set of decisions?

The different pedagogical activities will allow students to acquire different technical and managerial skills:

- Knowing how to design or transform the complex systems that are eco-neighborhoods by integrating the many stakeholders with different, even divergent, roles and interests,

- Take into account sustainable development parameters to ensure that the concept of eco-neighborhood is achieved

- Know how to design and plan large complex projects, which can be considered as multiple interdependent projects

Adviced prerequisites:

Sufficient level of French to be able to read and understand texts / articles in French and attend classes in French language without translation

Context and issue modules:

This part involves major players in the field who will share their vision and their roadmaps. It includes a presentation of the Plateau de Saclay development project by the EPA Paris Saclay, a visit to a development project that has been or is being carried out in the Ile de France region (and if possible in Paris), and a presentation of international projects by various players.

Specific course (60 HEE) : Sustainable urban planning and development

Brief description:

The specific course allows to approach the main disciplines which constitute the urban project, and to prepare the realization during the IE of the main deliverables produced during the design phase.

Disciplines: Initiation to the game of actors and the real estate value chain, smart city and sustainable city, urban and peri-urban agriculture, circular economy, energy issues, the Grand Paris Express and mobility, urban planning and eco-district reference.

Pedagogical methods: disciplinary courses are most often organized with a TD session which makes it possible to deepen the concepts seen in class, and to put into practice tools specific to each discipline: cartography, formalization of scenarios, territorial analysis.

Challenge Week : Design project for an eco-neighborhood - the case of Corbeville

Associated partner: -

Location: Paris-Saclay campus - site visit required

Brief description:

How to build the city? The city is made up of different structures: streets and public spaces, urban networks and energy in particular, public and individual transport, buildings and equipment... Complex project management tools are applied here to dissect the interplay of actors that allows the transformation of the city and to address all the disciplines and scales of territories to achieve these major projects.

The situation corresponds to one or several major (imaginary) modifying scenario(s): a 20-year delay of the metro line 18 or replacement of the metro by a tramway or any other scenario... . An urban design competition is launched to take into account this fundamental change.

The pedagogical objectives are the following:

- To handle on a concrete case the main concepts, methods and tools related to a complex project in the field of sustainable development and construction. The generic character and reusability to other contexts will also be important.

- Acquire a first set of knowledge related to the sectoral fields of urban planning, real estate development, smart grids and other urban networks, mobility (intermodality, and infrastructure) in particular.

At the end of the IE, students will have experienced the decision-making systems specific to urban development projects by having analyzed the key stages of specification, design and planning of such projects.

Deliverables: Diagnosis, modeling and exploration of alternatives, economic balance sheet, convergence of multiple coordinated decisions, schematization / representation, scenario of use situations, macro-plan.

2SC5410 – Sustainable urban planning and development

Instructors : **Frédérique Delmas-Jaubert**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **FRENCH**
Type of course : **Specific Course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

The specific course entitled Sustainable Urban Planning - AMUD - will provide the basic knowledge of the real estate and construction value chain, the emergence of smart cities. Traditional models of value creation are shaken, and new relationship between the circular economy, the city, and the environment appear.

Quarter number

ST5

Prerequisites (in terms of CS courses)

none

Syllabus

Human beings evolve in a framework that they help to shape: built environment, landscaped natural areas, transport infrastructures and public spaces are the ingredients of the living environment that we propose to study. These amenities and the behaviors of the men and women who live there have an impact on the natural resources of water, air and energy. All of these practices are today shaken by the rise of the digital economy.

"Ecoquartier" is a label by the French ministry of ecological transition

Introduction to the value chain and management of a construction operation
- Real estate development
- Urban scale
- Designers, contractors and other service providers: who does what?
- Economic value and environmental value

Management of complex systems

Circular economy applied to building processes

Smart city: GIS and user data
- Urban geography, a discipline that articulates spatial, temporal, human data ...
- The tools of Geographic Information Systems
- Graphic representation, dynamics and decision support
- Data property and digital business model

Smart city and Transports, le Grand Paris Express

Impact of urbanization on the water resource
- Effects of urbanization on the water resource
- Traditional and innovative techniques: industrial installations and alternative management

- Urban resilience and water risk management

the challenges of Agriculture, and urban agriculture

Energy
- Consumptions of buildings and new digital uses
- The question of scale and pooling: heat networks <> individual boilers
- Natural resources and their limits

Class components (lecture, labs, etc.)

This teaching includes:
- Lectures, delivered by different teachers on the campus of Gif
- In situ courses, traveling through a project area
- Thematic research to go deeper into a topic

Grading

- territorial diagnosis (note 9/20) : time slots reserved to work in group
- written control (1H30) (note 11/20)

Total (/20)

Resources

The teaching team includes urban and architecture specialists as Frédérique Delmas, François Cointe, Olivier Ledru and Arnaud Lafont, teachers-researchers as Franck Marle, Yann Leroy, Flore Vallet and François Cluzel.

Learning outcomes covered on the course

Three main purposes about stakeholders, issues and digital transformation of the city:
- By the end of the course, the student is able to identify stakeholders in real estate and urban project (C1.1), to analyse an urban project from different point of view, comparing the positions avec different stakholders (C4.1), to list social and environmental responsibilities of everyone, beyond their economic model (C9.2).
- By the end of the course, the student is able to link together the main economic, environmental, technical and human issues of an urban operation (C1.1) and to compare different kind of solutions (C3.6 et C9.4).
- By the end of the course, the student is able to report on the transformations of the urban services economy with the rise of the digital economy (C6.6).

Description of the skills acquired at the end of the course

C1.1 Examine a problem in full breadth and depth, within and beyond its immediate parameters, thus understanding it as a whole. This whole weaves the scientific, economic and social dimensions of the problem.

C2.1 Thoroughly master urban development domain, within every discipline involved and every scale.

C3.6 Evaluate the efficiency, feasibility and strength of the solutions offered.

C4.1 Think in client terms, identify and analyse customer needs, the constraints of other stakeholders as well as include societal challenges.

C6.6 Understand the digital economy applied to smart city concept and upheaval for traditional economic city actors

C9.2 Identify, within a given structure, the scope of liability as well as socio-ethical and environmental responsibilities.

C9.4 Demonstrate rigour and critical thinking in approaching problems from all angles, be they scientific, social or economic.

2SC5490 – Design project for an eco-neighborhood

Instructors : **Frédérique Delmas-Jaubert, Franck MARLE**
Department : **DOMINANTE - GRANDS SYSTÈMES EN INTERACTION, DOMINANTE - CONSTRUCTION VILLE TRANSPORTS**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The purpose of the integration project is to make the preliminary design of an eco-district.
Projects are carried out mainly in teams of 4 or 5 students. One project "Ecoquartier" is made by combination of 4 teams.
Each team should find solutions to satisfy several objectives (the eco-district referential). Some of these objectives are at the district level (urban shape, economic balance, ...).
Several deliverables are expected at all scales: individual level, team (sub-group), and group.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Specific module : sustainable urban planning

Syllabus

(if the case is confirmed)

The Corbeville ZAC: what future in the short, medium, and long term for this space near the interchange of the N118? A project was submitted by the EPAPS to a public inquiry in the spring of 2019. One or more significant parameters of the existing studies are modified (political orientation, mobility solutions, the ambition of density, ...). We propose to analyze the consequences of these changes on the urban project.

Input data :
- Historical aerial photo
- Maps available on geoportal (in particular IGN with topography, watercourse, and existing building)
- Insee data available online
- Program and guide EPAPS of the district of Moulon

Class components (lecture, labs, etc.)

Sprint-based project (3 sprints of 1,5 days each).
Self-organized and connected teams within the group, sprint reviews with each group supervisor.
Opportunity to get specific expertise during some sessions.
Deliverables must be done throughout the week (detailed schedule presented the first day).

Grading

Continuous assessment, based on group deliverables. An individual deliverable is also assessed.

Resources

Supervisors and experts are professors, architects, urbanists, engineers, researchers, ...
Franck Marle, Frédérique Delmas, Ulisse Vizzardi, Romain Iliou, François Cointe, François Cluzel, Arnaud Lafont,

Learning outcomes covered on the course

Upon completion of this module, students will progress in:
- using a transdisciplinary approach to complex eco-districts design
- using scientific, technological, social, and economic knowledge to design and validate such a complex system
- applying a collaborative project management approach to attain desired results

Description of the skills acquired at the end of the course

C1.4 Design, detail and corroborate a whole or part of a complex system.
C1.5 Bring together broad scientific and technical concepts in a core structure that is nestled in an interdisciplinary approach.
C3.6 Evaluate the efficiency, feasibility and strength of the solutions offered.
C7.1 Persuade at the level of core values; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. To make the added value known.
C9.4 Demonstrate rigour and critical thinking in approaching problems from all angles, be they scientific, social or economic.

ST5 - 55 - LIGHT ANS MATTER : DEVELOPMENT OF HIGH TECHNOLOGY INSTRUMENTS

Dominante : PNT (Physics & NanoTechnology)

Langue d'enseignement : French

Campus où le cours est proposé : Paris-Saclay

Engineering problem

Modern physics has many outlets through the control of the properties of matter and its functional engineering. In this ST, students will be confronted with the problem of innovation and product development when it is a high-tech instrument using physics, developed in small series for research or R&D. In particular, the students will answer the following questions
- how to qualify and respond to a customer need in this context?
- which approach to design, realization and evolution to implement?
- how to design a solution for an intermediate customer who has customers with various needs?

The integration courses concern devices at the cutting edge of physics requiring a real engineering approach since the theoretical concepts are applied to real devices that must integrate elements of feasibility both technical and economic.

Adviced prerequisites

It is recommended to have taken the SPI course of Wave Physics or Transfer Science

Context and issue modules:

This part is structured around half-day training sessions aimed at presenting the sequence, the integration lessons and introducing the theme. The following lectures/presentations will be organized:
- Presentation of the theme and its challenges
- Round-table discussion on professions: What is a physics engineer?
- Visit of a company
- Presentation of the EI

Specific course (60 HEE) : Physics of Matter

Brief description: The course will provide students with a basic understanding of the physics of solid state matter. Crystallography and wave diffraction (especially X-rays), lattice vibrations (phonons, thermal effects), electronic states (Sommerfeld model, band theory), as well as specific topics: semiconductors, defects, superconductivity will be covered. The goal is to show students that the understanding and control of material properties requires studies at the microscopic scale**.**

Challenge Week n°1 : Synchrotron Beamline Design

- Associated partners: European Synchrotron Radiation Facility (ESRF, Grenoble), SOLEIL synchrotron (Gif-sur-Yvette), NSLS synchrotron (Brookhaven, USA)
- Location: Paris-Saclay campus

Brief description: the objectives are the following:
- To dimension a device using basic (modern) physics notions and to do functional modeling.
- Identify the relevant heat transfers, model them, and size these systems.
- Know the key points of a pre-project study in a multidisciplinary context
- Have realistic orders of magnitude on the standard mechanical and physical properties of "common" materials.
- Carry out a preliminary design of the scientific instruments studied, justifying the choices made.
- Work in a team, know and be able to identify the different roles of the members of a team, lead and coordinate a work group, collect and share information, format and present the work done (express oneself in front of an audience / defense)

2SC5510 – Physics of matter

Instructors : **Hichem Dammak**
Department : **DÉPARTEMENT PHYSIQUE**
Language of instruction : **FRENCH**
Type of course : **Specific Course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

The course aims to provide students with the basic knowledge of solid-state physics. Using specific examples from advanced sectors, such as nanosciences or optoelectronics, the goal is:
- to introduce them to this vast and rich physics field,
- give them the tools that will allow them to confront with confidence the many challenges that this field will bring to tomorrow's applications.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Quantum Physics course
Statistical Physics course
Electromagnetism in vaccum

Syllabus

Course syllabus:
• Order in solids: the crystal lattice.
• Scattering of waves by the crystals: diffraction.
• Metals and conductivity: Drude and Sommerfeld models.
• Band structure: electrons in bulk crystals and in nanostructures.
• Semiconductors – Quantum wells: applications in optoelectronics.
• P-N junction (diode)

• Phonons and thermal properties.

Class components (lecture, labs, etc.)

Lectures (13.5 hours), tutorials (15 hours).

Grading

Final exam (FE): Written exam (1h30) without documents with a provided form.
Continuous assessment (CA) : 3 Quizzes of 10 minutes at the beginning of a class session
Final grade: FG=0.35 CA + 0.65 FE
Grade Session 1: Max(FG,FE)

Validation of the C1 skill: Score in one of the two indicated exercises of the final exam is higher or equal to 50%.
Validation of the C2 skill: The mark of the session 1 is higher or equal to 50%.

Session 2:
Written exam (1h30) without documents with a provided form. The grade of session 2 will not take into account the CC mark.

Course support, bibliography

Handout
Solid-state physics, Ashcroft and Mermin
Solid-state physics, Kittel

Resources

Teaching staff: H. Dammak, B. Dkhil, J.M. Gillet

Learning outcomes covered on the course

At the end of the course, students are expected to know:
1) Determine the crystal system and Bravais lattice of a crystal and specify the lattice multiplicity chosen from a geometric data of a lattice of atoms.
2) Express the inter-reticular distances using Miller indices.
3) Apply Bragg's law to analyze the results of a diffraction experiment using X-rays, neutrons or electrons.
4) Identify, among the phonon dispersion relation curves along a direction of the reciprocal lattice, the optical, longitudinal acoustic and transverse acoustic branches as well as its degeneracy.
5) Apply the free electron model to determine the electronic states in a quantum well in 1D or 2D.
6) Apply the free electron model to calculate the density of electronic states and the Fermi energy.
7) Apply the free electron model to determine the contribution of electrons to the specific heat.
8) Identify, from the electron energy dispersion relations, the metallic, insulating or semiconducting character of a crystal.
9) Determine the carrier density in an intrinsic or doped semiconductor from a model of the valence and conduction band electron density curves.
10) Describe the equilibrium of a P-N junction (diode).
11) Determine the density of phonon states in the Debye model in 1D, 2D or 3D.
12) Calculate the contribution of phonons to the specific heat using the Debye model.

Description of the skills acquired at the end of the course

C1.2: Modeling: use and develop appropriate models, choose the right scale of modeling and relevant simplifying assumptions (outcomes 5-9)
C1.3: Apply problem-solving through approximation, simulation and experimentation (outcomes 1-4,10-12)
C2.1: Deepen your knowledge of an engineering field or scientific discipline

2SC5591 – Synchrotron Beamline design

Instructors : **Pierre-Eymeric Janolin**
Department : **DOMINANTE - PHYSIQUE ET NANOTECHNOLOGIES**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This is a multidisciplinary course. Teams of about 20 students are challenged with understanding, designing, and scaling the physical, mechanical, heating, and materials aspects of key technological components of a synchrotron beamline. The use of CAD tools is encouraged and students that would not be familiar with these tools will be taught how to use them.
Each team shall be supported by experts working in French and European synchrotrons, through daily video interviews.
One of the team shall design a beam line able to perform angiography on a human patient, another shall design a beam line able to detect the presence of a cancer-inducing isotope of Chromium in a frog ovarian cells and the third one shall design a beam line enabling diffraction on solar panels made out of hybrid perovskites.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Basic knowledge in modern physics and heat transfer. Mechanical engineering skills will be useful

Syllabus

- This module is a project-based learning activity, with emphasis on the following topics:
- Crystallography, radiation by an accelerated particule, fluorescence, absorption, scattering, diffraction of short wavelength radiation
- Heat transfer: convection, radiation, conduction, fluid mechanics
- Computer-Aided Design (CAD), numerical modeling, design pre-project, pre-scaling of mechanical systems.
- Selection of materials, standard mechanical properties, strength of materials in an extreme environment, surface states, elaboration and shaping processes
- Experiencing teamwork under time pressure, chairing a meeting, oral expression

Class components (lecture, labs, etc.)

Students will work in project mode during the challenge week.
The students enrolled in this course must attend the final presentation, usually at synchrotron SOLEIL. A visit of SOLEIL is also scheduled.

Grading

1/2 on the involvement during the week (evaluated by the profs as well as the other team members) and evaluation of the C1, C2, C4, C6 skills

1/4 on the final presentation (one presenter per group, everybody in the group gets the same grade) and evaluation of the C7 skill
1/4 on the final report (common grade for the entire team) and evaluation of the C7 skill

Course support, bibliography

Reference textbooks and databases shall be made available during the week.

Resources

The use of CAD tools (e.g. SPACECLAIM or SOLIDWORKS) is encouraged. Students who wish to learn these tools will be given access to a license of SPACECLAIM and will be provided with online tutorial sessions. Alternate design tools (drawings, models,...) are also very useful, in particular for the design of specific components of the beamline.

Learning outcomes covered on the course

1. to apply design concepts using basic notions of modern physics
2. to identify the key heat transfer modes to model and design systems.
3. to know the key points for a pre-project study in a multidisciplinary context.
4. to be familiar with realistic orders of magnitude for the physical and mechanical properties of standard materials.
5. to understand orders of magnitude for mechanical and physical properties of usual materials
6. to develop teamwork abilities, know and identify different roles in a team; manage a workgroup, collect and share information, shape and defend the results of the work in front of an audience / a jury.

Description of the skills acquired at the end of the course

C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 : Develop in-depth skills in an engineering field and a family of professions
C4 : Have a sense of value creation for his company and his customers
C6 : Be operational, responsible, and innovative in the digital world
C7 : Know how to convince

ST5 - 56 - MULTI – ENERGY SYSTEMS

Dominante **:** ENE (Energy) and GSI (Large Interacting Systems)

Langue d'enseignement **:** French

Campus où le cours est proposé **:** Paris-Saclay

Engineering problem

The objectives of reducing energy consumption and polluting emissions make it necessary to use energy systems that call on sources with complementary yields and characteristics. This is the case for electricity production systems, where the growth of intermittent renewable production requires more flexibility from conventional production means, and also for the transport sector, where electric and thermal engines complement each other advantageously.

These multi-energy systems require advanced control modes to take advantage of the complementarity of energy sources, and to satisfy the needs of users and the economic, technical and environmental constraints.

Advised prerequisites

It is strongly advised to have taken at least one of the SPI Transfer Sciences or Electrical Energy courses.

Context and issue modules:

This part is organized around half-days of training aiming to present the sequence, the integration teaching and to introduce the stakes and associated bottlenecks, in particular under the economic aspects and related to the social and geopolitical environment of the topic.

Specific course (60 HEE) : Introduction to energy production

Brief description: the course is structured in two parts:

1. Mechanical energy production

- Internal combustion engines: introduction to internal combustion engines (architecture, thermodynamic cycle, operation and control, pollutant emissions, basic sizing)

- Turbomachinery (wind turbines, hydraulic turbines, gas turbines): introduction to turbomachinery (architecture, operation, control modes, interest)

2. Electrical energy conversion

- Structure of alternating current machines, motor/generator operation

- Electronic converters.

- Principles for speed variation of machines (machine and converter system)

Challenge week n°1: Regulation and control of energy production and conversion systems

Associated partners: EDF, GE Converteam

Location: Paris-Saclay campus

Brief description:

The objectives are :

- To be able to model an industrial physical system for a control purpose

- Understand the impact of the regulation of an installation on the overall operation of the electrical system

- To do functional modeling to determine the control strategy of a system

- Be able to develop a control law that meets the specifications

- Take into account the specificities of the conversion elements to associate them and create a system

Challenge week n°2: Hybrid powertrain

Associated partner: to be confirmed

Location: Paris-Saclay campus

Brief description:

The objectives are :

- Implement a systemic model of the hybrid powertrain

- Implement numerical processing tools under Matlab/Simulink

- Implement a control approach of the whole hybrid chain from the driver to the wheels

- Introduction to cycle sizing: complexity of the system and contradiction of several objectives to be achieved

Challenge week n°3: Hybrid aeronautical propulsion

Associated partner: Safran Tech

Location: Paris-Saclay campus

Brief description:

The integration course deals with power management in the context of a small single-engine aircraft with a hybrid battery/fuel cell energy architecture. The aircraft is propelled by a propeller powered by an electric motor and electricity is either directly drawn from batteries or generated by the combination of H2 and O2 in a fuel cell. The objectives are as follows:

- Realize a part and then assemble the whole systemic model of the energy architecture of the considered hybrid aircraft

- Implement the numerical resolution tools via Simulink and analyze the data collected

- Develop the regulation strategy of the system according to the given constraints

- Critique the model used in relation to the state of the art

2SC5610 – Introduction to energy production

Instructors : **Adrien Voldoire, Romaric Landfried**
Department : **DÉPARTEMENT SYSTÈMES D'ÉNERGIE ÉLECTRIQUE**
Language of instruction : **FRENCH**
Type of course : **Specific course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

To reduce energy consumption and polluting emissions it’s necessary to use energy systems that includes sources whose efficiency and characteristics are complementary. This is true for electricity generation systems, where the growth of intermittent renewable generation requires more flexibility from conventional means of production, and also from the transport sector, where the electric and thermal powertrains complement each other advantageously.
These multi-energy systems require advanced control modes to take advantage of the complementarity of energy sources, and satisfy user needs and economic, technical and environmental constraints.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Transport Phenomena, Electric energy

Syllabus

1. Thermal energy conversion
Turbomachines (turbojets, turboalternators)
Internal combustion engines

2. Electrical energy conversion
Introduction to structure of AC machines, motor / generator operation
Electronic converters.
Principles for speed variation of machines (machine system and converters)

Class components (lecture, labs, etc.)

Thermal energy conversion (session 1 to 9)

Electrical energy conversion (session 10 to 19)

CC : Core Curriculum
T : Tutorial

Grading

Exam at the end of the course for 1 hour and a half.

Course support, bibliography
Documents online on Edunao

Resources

Teaching staff: Maya Hage Hassan, Antoine Renaud, Pierre Duquesne (Centrale Lyon), Adrien Voldoire, Romaric Landfried
Size of tutorial classes (default 35 students): 25
Tutorials in classical auditorium and computer rooms

Learning outcomes covered on the course

At the end of this course students will be able to
Understand the basics of energy conversion systems in mechanics and electrical.
Understand different ways of converting thermal energy into mechanical one (internal combustion engine, turbomachine).
Identify the strengths and constraints of these different modes of energy production as well as to propose first elements of pre-sizing.
Propose a fast modeling of synchronous and asynchronous machines and converters and also to identify some machine / converter systems for hybridization applications, with regards to the electrical portion of the course.

Description of the skills acquired at the end of the course

Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem
Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem
Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation
Design, detail and corroborate a whole or part of a complex system
Create knowledge within a scientific paradigm
Master the skillset of a core profession within the engineering sciences (at junior level)
Be proactive and involved, take initiatives
Act ethically, with integrity and respect for others
Demonstrate rigour and critical thinking in approaching problems from all angles, be they scientific, social or economic

2SC5691 – Regulation and control of energy production and conversion systems

Instructors : **Guillaume Sandou**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This "Challenging Week" entitled "Energy production and conversion" aims to tackle the regulation issues of several electrical energy production units, linked to the transport or distribution network. The considered systems to be studied will be for instance (list to be confirmed when the project subjects will be available) an hydroelectric production unit, a wind farm, a cogeneration or a photovolatic production unit.
The work to be done will be divided into few main steps:
- development of a model of the energy production unit based on given documents and data
- design of a control law for the production unit in face with specifications well suited to the considered problem
- Validation based on simulations of the regulation law.
These studied will be partly carried out in collaboration with EDF and in particular with the "Centre d'Ingénierie Hydraulique" located in Bourget-du-Lac.
Depending on the considered case, the work will consist in reproducing the observed behaviour of the controlled production unit, enhancing the performance of the regulation, or investigating an innovative operating mode for the production unit.

Quarter number

ST5

Prerequisites (in terms of CS courses)

- Control Theory (Second year core module, ST5)
- Introduction to energy production (module in the Engineering Challenge Term ST5 "Multi-energy systems")

Syllabus

Outline of the Challenging Week :

- First half-day: presentation and choice of the projects
- Half-days 2 to 8 : project completion
    - Handling of the proposed issue and corresponding available documents and data
    - Design of a nonlinear simulator for the open-loop production unit
    - Determination of a model well suited to control purposes
    - Computation of the control law in face with dedicated specifications for the considered unit
    - Definition, if possible, of an innovative control law strategy
    - Validation based one the nonlinear simulator
- Last half-day: oral presentation of the results

Half-day 4 will be carried out in an "offsite hour" mode

Class components (lecture, labs, etc.)

Project, made by groups of 4 or 5 students.
Supervision by teachers from CentraleSupélec.

Grading

Each group of 4 or 5 students should provide:
- a full simulator of the work done, including a non linear simulator of the system, control law and validation files;
- a report explaining the proposed approach and in particular the way to use the simulator and the codes;
- an oral presentation of the work

Skills C1, C2 and C6 will be specifically assessed
"C1 Analyze, design and build complex systems with scientific, technological, human and economic components", in particular by justifying the approach adopted
"C2 Develop in-depth skills in an engineering field and in a family of professions", in particular by analyzing the results obtained with regard to the application in question
"C6 Being operational, responsible and innovative in the digital world", in particular through the deliverables (simulators)

Course support, bibliography

N. Gionfra, H. Siguerdidjane, G. Sandou, D. Faille, and P. Loevenbruck. Combined Feedback Linearization and MPC for Wind Turbine Power Tracking. 2016 IEEE Multi-Conference on Systems and Control, International Conference on Control Applications, Buenos Aires, Argentina, September 19th-22nd, 2016.
Boubekeur Boukhezzar and Houria Siguerdidjane. Nonlinear Control of a Variable-Speed Wind Turbine Using a Two-Mass Model. IEEE Transactions on Energy Conversion, vol. 26, no. 1, Mars 2011.
Morten Hartvig Hansen and Lars Christian Henriksen. Basic DTU Wind Energy controller. DTU Wind Energy E-0018. January 2013.
Gérard Robert, Frédéric Michaud. Reduced Models for Grid Connected Hydro Power Plant Application to Generation Control. International Conference on Communications, Computing and Control Applications. 3-5 March 2011. Hammamet, Tunisia
Nicola Femia, Giovanni Petrone, Giovanni Spagnuolo, and Massimo Vitelli. Optimization of Perturb and Observe Maximum Power Point Tracking Method. IEEE Transaction on Power Electronics, Vol. 20, No. 4, July 2005
Rae-Young Kim, and Jih-Sheng Lai. Seamless Mode Transfer Maximum Power Point Tracking Controller For Thermoelectric Generator Applications. IEEE Transaction on Power Electronics, vol. 23, no. 5, September 2008

Resources

- Teachers from the Control Department and Energy Department;
- Contacts and meetings with research engineers from EDF;
- Documents and data about electricity production units;
- Use of students' laptops

Learning outcomes covered on the course

At the end of this module, students will be able to
- Model a physical and industrial system for control purposes;
- Capture the impact of a production unit regulation ob the global operation of the electrical system;
- Model a system, from a functional point of view , so as to determine the control strategy;
- Develop a control law in face with some specifications;
- Take into account the specificities of some energy production units;
- Validate the behaviour of a controlled electricity production unit.

Description of the skills acquired at the end of the course

C1.1 Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem

C1.2 Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem
C1.3 Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation
C1.4 Design, detail and corroborate a whole or part of a complex system
C2.1 Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.
C3.6 Evaluate the efficiency, feasibility and strength of the solutions offered. / proposed solutions
C3.7 Make pragmatic and informed choices with the aim of producing tangible results.
C7.1 Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. Highlight the added value
C8.1 Work collaboratively in a team

2SC5692 – Hybrid power train

Instructors : **Adrien Voldoire, Romaric Landfried**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The objective of this project is to propose a model and a regulation of a hybrid drive train (electric and thermal) for vehicles.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Electric energy

Syllabus

1. Presentation of the different elements of the hybrid power train :
Introduction to the environmental, economic constraints
Presentation of ways to increase the overall efficiency of the powertrain and the structure of a hybrid drive train
Presentation of the combustion engine, structure of the automotive industry
Control of electrical machines (choice between MCC and synchronous machine), for integration in a system model
2. Application and development of a numerical model :
Presentation of the hybrid system model in Simulink :
Implementation of the different parts of the block diagram: car model, combustion engine, gearbox, electric motor coupling, batteries.
Presentation of a flow management strategy on WLTP consumption cycle.

Class components (lecture, labs, etc.)

Project by group of 4 or 5 students

Grading

final defense and report

Course support, bibliography

Supports given during the lesson and during the project

Resources

Modeling on Matlab
Scientific publications

Learning outcomes covered on the course

- Implementing a systemic model of the electric powertrain and then a hybrid powertrain
- Implementing digital processing tools under matlab/Simulink

- Implementing a control approach for the entire hybrid chain from driver to wheels
- Introduction to cycle dimensioning: complexity of the system and contradiction of several objectives to be achieved

Description of the skills acquired at the end of the course

Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem
Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem
Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation
Design, detail and corroborate a whole or part of a complex system
Create knowledge within a scientific paradigm
Master the skillset of a core profession within the engineering sciences (at junior level)
Be proactive and involved, take initiatives
Act ethically, with integrity and respect for others
Demonstrate rigour and critical thinking in approaching problems from all angles, be they scientific, social or economic

2SC5693 – Hybrid aeronautical propulsion

Instructors : **Antoine Renaud**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRENCH**
Type of course : **Challenge Week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The electrification of aviation is a topical issue, given the challenges of reducing polluting emissions to which the air transport community has committed itself: by the middle of the 21st century, the aim is to halve CO_2 emissions from all air traffic. At the same time, it is estimated that the volume of passengers carried will almost double.

In this context, it is legitimate to focus on electrically-powered aircraft, which raises the problem of energy storage: batteries are still very heavy and are barely sufficient to move light aircraft with two passengers over a few hundred kilometers.

During this challenge week, we will focus on a light aircraft of the high-end ultralight class. For this category of aircraft, we can already consider electrification of the propulsion with existing technologies. We will consider a hybrid architecture combining a battery with a hydrogen fuel cell.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Transport phenomena or Electrical energy courses

Syllabus

A general Simulink template of the model will be provided, with a number of blank sub-templates that will need to be completed. Validation tests will then have to be carried out on each of the sub-systems.

1. Fuel Cell

1. Battery core electrochemistry
2. Thermal management
3. Sequencing logic

2. Electrical distribution and motorization

1. Engine and its regulation
2. Battery and its management system
3. Power regulation

3. Airframe

- Flight mechanics and taxiing
- Control loops and piloting

4. Preparation of the test procedure

- Definition of mission profiles
- Pre- and post-processing

In a second part, the groups will be redistributed into three teams and the models of the sub-systems will be shared. Each team will be in charge of assembling its aircraft and testing it.

Class components (lecture, labs, etc.)

The work will be supervised by speakers from SafranTech as well as CentraleSupélec teachers. Students will be divided into groups and sub-groups according to the different tasks to be accomplished. Reconfigurations will take place during the week according to the progress of the work.

Grading

The evaluation is based on attendance, motivation and efficiency throughout the week as well as on two group presentations, one in the middle of the week and the second on the last day.

Resources

The whole activity will take place using Matlab/Simulink software to simulate the problem.

Learning outcomes covered on the course

By the end of the week, students will have learned about flight mechanics, how to fly an airplane, and how electric motors and fuel cells work. Most importantly, they will have learned how to manage the constraints associated with these different elements when they are assembled in a complex system. Finally, the scope and complexity of the problem necessarily require teamwork with different core businesses, replicating real-life work situations.

Description of the skills acquired at the end of the course

C1.3: Apply problem-solving through approximation, simulation and experimentation.
C1.4: Design, detail and corroborate a whole or part of a complex system.
C2.3: Rapidly identify and acquire the new knowledge and skills necessary in applicable/relevant domains, be they technical, economic or others.
C7.1: Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. Highlight the added value.
C8.1: Work collaboratively in a team

ST5 - 57 - CONTROL OF ACOUSTIC AND ELECTROMAGNETIC POLLUTION

Dominante : MDS (Mathematics, Data Science) and Info&Num (Computer Science and Digital)

Langue d'enseignement : French

Campus où le cours est proposé : Paris-Saclay

Engineering problem

Noise pollution is nowadays considered as a major annoyance by the population, while electromagnetic pollution raises many questions and interrogations related to health problems. The practical realizations allowing to control this pollution represent a technical and industrial challenge of the first rank, but do not yet benefit from the new developments that mathematical analysis, numerical simulation and data processing can bring.

This course focuses on the design of innovative products (acoustic or electromagnetic coatings) intended to control acoustic/electromagnetic pollution. Having introduced the physical context, it aims to give students the mathematical and computer science notions associated with the design and manufacture of such products. This teaching proposes two paths of training:

1. Mathematical Methods Track: a track based on mathematical theory (PDEs, functional analysis, Fréchet derivative) associated with numerical algorithms to master the control of waves to define the shape of an acoustic or electromagnetic coating. In particular, in this track are treated the PDEs on irregular edges (fractals) and is developed the method of optimization of shapes and the notion of the derivative with respect to the edge.

2. Scientific Computing, numerical methods and algorithms: the objective of this track is to deepen the numerical methods used in the mathematical track, it is oriented towards scientific computing. By focusing on the same common goal as the mathematical track, this track allows to go further in the numerical implementation of the method of optimization of forms.

Both tracks study methods (theoretical or numerical) that are useful for controlling external acoustic waves (in the vicinity of highways, airports, construction sites) or internal acoustic waves (sound insulation in offices by perforated panels or acoustic liners in aircraft engines for example), as well as for controlling electromagnetic pollution (anechoic chambers).

The integration course allows students to apply the skills and knowledge acquired in the case of a chosen application to guarantee the best performance while taking into account regulatory, environmental and economic constraints.

The intervention of industrialists (ONERA, SIEPEL) and specialists in the design of anti-noise walls allows a better understanding of the economic constraints and issues associated with the design and operation of innovative products.

Adviced prerequisites

For the "Mathematical Methods" track, mastery of the first year PDE course is required. From a general point of view, having followed the SPI course "Physics of Waves" would be a plus.

Context and issue modules:

This part is organized around half-days of training aimed at presenting the sequence, the integration teaching and introducing the issues and associated locks. Thus, the following topics will be addressed: fractals for innovation in

acoustic and electromagnetic applications, control by acoustic liners in aeronautical engines, current challenges in the control of electromagnetic waves, research and innovation in the control of waves.

Specific course (60 HEE) :

Wave control: theory and algorithmic

Brief description: The two proposed tracks have the same objectives. The concepts of the common course of Automatic are deepened in the context of the control of the dissipation of the energy of a wave. The observability in this case depends on the geometry of the absorbing edge. To illustrate the reasons why geometric irregularity is needed, the notions of fractal geometry are introduced with results known in physics and, for the theoretical way, in mathematics. In particular, we present the phenomena of localization and absorption of waves (acoustic or electromagnetic) which are linked by the spectral analysis of the model (theoretical and numerical). In order to better understand the environmental and sociological stakes of the development of acoustic barriers, some psycho-acoustic aspects are presented, which show the importance of the dissipation of certain frequencies. The course studies in particular, for a fixed frequency, the obtaining of an optimal form for a frequency model via the Helmholtz equations with the aim of allowing its use in AR on two types of control: geometric and topological. For the numerical path, the algorithmic part of this method will be presented in detail. In the mathematical path, these numerical methods will also be presented but much more briefly.

We then consider the main difficulty of having a "near optimal" shape over a large frequency band, important from a psycho-acoustic point of view and from industrial interests. The final goal in AR is to be able to quickly and robustly determine the optimal or "near optimal" shape of the geometry over a frequency band by numerical simulation.

The two proposed tracks include a joint numerical project on eigenmode localization and two different examination topics.

Challenge week n°1:

Design of a cladding to control wave pollution Control of external acoustic pollution

Associated partner: ONERA

Location: Paris-Saclay campus

Brief description :

We position ourselves on the industrial issues that impose economic constraints and technological constraints necessary for the improvement of existing products on the market, to design innovative coatings to absorb noise from aircraft, trains, cars. The aim is to develop these innovative products in an optimal way by controlling the energy of the waves through the geometry of the wall while taking into account the economic constraints. For example, COLAS and École Polytechnique have developed a noise barrier called "Fractal Wall" TM, which was empirically designed with a complex geometry to dissipate the different wavelengths. However, this wall, even if it is four times more efficient than conventional walls for low frequencies, is hardly sold... The explanation lies in the fact that its construction, being done by demolding, risks breaking the wall, which results in a high manufacturing cost. This AR proposes to find, by wave control methods, optimal shapes as absorbent as possible (in decibel) which satisfy the constraints imposed by the industrialist, for example, the lowest manufacturing cost with the highest decibel reduction. First numerical results in this context show the existence of optimal shapes "not too complex" able to improve by a factor of 6 the performances of the "Fractal wall" TM.

Challenge week n°2 :

Design of a cladding to control wave pollution. Control of indoor acoustic pollution

Associated partner: ONERA

Location: Paris-Saclay campus

Brief description :

We are positioned on the industrial issues that impose economic constraints and technological constraints necessary to improve existing products on the market, in order to design interior coatings to absorb noise inside buildings and also acoustic liners in aircraft engines. In this context we are interested in three main applications: (i) the design of liners in anechoic chambers (so far acoustic anechoic chambers have been designed empirically based on geometries using different scales), (ii) the design of perforated absorbing panels (absorbing materials are made of fibers that have very good absorbing acoustic properties, and are usually covered with wooden panels for aesthetic reasons, which unfortunately impairs their effectiveness) and finally (iii) perforated absorbing insulators in aircraft engines. In the last application it is important to optimize the diameter and positioning of the holes in the material. The objectives are to control the waves as well as possible by an analysis of the optimal shape of the surface of these coatings in order to improve the acoustic absorption in decibel by taking into account the industrial stakes and constraints.

Challenge week n°3:

Design of a coating to control wave pollution. Control of electromagnetic pollution

Associated partner: ONERA

Location: Paris-Saclay campus

Brief description :

We position ourselves on the industrial stakes, presented by SIEPEL, which impose the economic and technological constraints necessary to improve the existing products on the market, in order to absorb the electromagnetic waves. As fields of application, we aim at the design and the optimization of an anechoic chamber. We notice that the absorbing materials for electromagnetic waves are different from the dissipative materials for acoustic waves. The different nature of these waves implies an adaptation of the model seen in class.

2SC5710 – Theory and algorithmics for wave control

Instructors : **Anna Rozanova-Pierrat**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **FRENCH**
Type of course : **Specific Course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

Acoustic pollution is today considered a major annoyance by the population, while electromagnetic pollution raises many questions and questions related to health problems. Practical achievements to control this pollution represent a major technical and industrial challenge, but do not yet benefit from the new developments that mathematical analysis, numerical simulation and computer science can bring to it.

This course focuses on the design of innovative products (acoustic or electromagnetic coating) intended to control acoustic / electromagnetic pollution.
Having introduced the physical context in the "Context and challenges" module, it aims to give students the concepts in mathematics and computer science associated with the design and manufacture of such products.
This course offers two training paths:

1) Theoretical analysis path, directed by Ms. Rozanova-Pierrat: a path based on mathematical theory (EDPs, functional analysis, derived from Fréchet) to master the control of waves to define the form of an acoustic or electromagnetic coating. In particular, in this way are treated the EDPs on the irregular edges (fractals) and is developed the method of optimization of the forms and the concept of the derivative compared to the boundary.

2) Digital analysis path, numerical and algorithmic methods, directed by M. Magoulès: this path aims to deepen the numerical methods, it is oriented towards scientific calculation. In particular, in this way are treated the numerical methods and the implementation of these for the propagation of the waves and the method of optimization of the forms.

The two tracks prepare for the three EIs proposed subsequently. More precisely, they study the methods (theoretical or numerical) which are useful for the themes of the three EIs: for controlling external acoustic waves (near motorways, airports, construction sites) or internal (sound insulation in offices by perforated panels or acoustic liners in aircraft reactors for example), as well as in the control of electromagnetic pollution (anechoic chambers).

Quarter number

ST5

Prerequisites (in terms of CS courses)

Knowledge of SG courses of the 1st year: Algorithmics and complexity (for the Scientific Computing track) and EDPs (for the Mathematical Methods track)
SPI course "Wave Physics" is recommended for the EI "Electromagnetic pollution control"

Syllabus

The control problems described by partial differential equations (observability, controllability, controllability) are developed in the course of the "Automatique et Contrôle" of the ST, which is further explored in the context of the

control of the dissipation of the wave energy. The observability in this case depends on the geometry of the absorbing edge. To illustrate the reasons for requiring geometric irregularity, we introduce the notions of fractal geometry with known results in physics (for two tracks) and mathematics (for the track "Theoretical analysis"). In particular, we present the phenomena of localization and absorption of waves (acoustic or electromagnetic) which are connected by the spectral analysis of the model. To better understand the environmental and sociological issues of acoustic barrier development, we present some psychoacoustic aspects, which show the importance of the dissipation of certain frequencies. The course studies in particular, for a fixed frequency, obtaining an optimal form for a frequency model on the Helmholtz equations in order to allow its use in the IE on two types of controls: geometric and topological. We then consider the main difficulty of having an "almost optimal" shape over a wide band of frequencies, important from a psychoacoustic point of view and industrial interests. In this context are also presented the most suitable numerical methods (thoroughly for the track "Scientific computing") in order to quickly and robustly determine the optimal shape or the "almost optimal" shape of the geometry on a frequency band by numerical simulation.

Course outline per session: 1) Course/TD on the common theme of two
tracks with adapted levels of presentation:
EDPs introduction: Delta operators, nabla, div, edge of a domain, an external normal, integration by parts. Wave propagation models.
2) Course/TD a) Theoretical Analysis track: Traces, extensions, compact sets, compact operators. Poisson equation.
b) Numerical Analysis track: Poisson equation, finite element method, finite difference method, numerical implementation.
3) Course a) Theoretical Analysis track: Fractal boundary. Analysis of the Poisson problem with mixed boundary conditions and the associated spectral problem.
b) Numerical Analysis track: Pre-fractal boundary. Spectral problem and associated numerical methods, implementation of the different boundary conditions, numerical error.
4) Course/TD a) Theoretical Analysis track: Helmholtz model with an absorbing edge, its theoretical resolution and dependence on the acoustic energy of the frequencies
b) Digital Analysis track: Advanced numerical methods in the context of waves
5) Course/TD on the common theme in two ways: Numerical resolution of the Helmholtz problem with edge dissipation and the associated spectral problem. Machine and TP tutorials: Launch of the numerical project for two tracks
6) Course a) Theoretical Analysis track: Parametric optimization (existence of an optimal form)
b) Digital Analysis track: Introduction of parametric, algorithmic and associated digital optimization
7) Course a) Theoretical Analysis track: Fréchet derivative and the derivative with respect to a parameter. Lagragian method.
b) Numerical Analysis track: Concept of the Fréchet derivative. Numerical implementation of parametric optimization
8) Course/TD a) Theoretical Analysis track: Optimization of forms. Shape derivative.
b) Digital Analysis track: Introduction to optimizing shapes. Numerical implementation of shape optimization
9) Course with an adaptation to the two paths: Numerical algorithm of the optimization of the forms and the optimality on a range of frequencies. Wave control, link with th commun "Automatic" course.

Class components (lecture, labs, etc.)

Cours 15*1h30, TD 4*1h30, project (not included in TDs, help during the office hours), handbook of the course, computations on a cluster, solutions of exercises of TDs

Grading

Final exam 1h30 evaluated as 70% in the final note and the project evaluated as 30% in the final note for the Theoretical Analysis Track.

Numerical project evalueted as 70% in the final note and the project evaluated as 30% in the final note for the Numerical Analysis Track.

Course support, bibliography

1. *F. Magoulès, P.T.K. Ngyuen, P. Omnes, A. Rozanova-Pierrat, Optimal absorbtion of acoustic waves by a boundary} SIAM J. Control Optim. Vol. 59, No. 1, (2021), pp. 561-583.*

2. *Kevin Arfi, Anna Rozanova-Pierrat. Dirichlet-to-Neumann or Poincaré-Steklov operator on fractals described by d-sets. Discrete and Continuous Dynamical Systems - Series S, American Institute of Mathematical Sciences, 2019, 12 (1), pp.1-26.*

3. *G. Allaire Conception optimale de structures, Springer.*

4. *A. Henrot, M. Pierre Variation et optimisation de formes. Une analyse géométrique. Springer.*

5. *M. Filoche and S. Mayboroda, Universal mechanism for Anderson and weak localization, Proceedings of the National Academy of Sciences of the USA 109, 14761 (2012).*

6. *M. Filoche and S. Mayboroda, The landscape of Anderson localization in a disordered medium, Contemporary Mathematics, 601 (2013), 113-121*

Resources

Students are divided into two groups (by the choice of students) corresponding to two mentioned tracks before the start of the specific course. Each group has courses intended to introduce concepts used in TDs and in the longer term in IE (the three IEs offered). There will be some courses on numerical methods in the mathematical way and there will be some basic theoretical courses (such as multidimensional integration) in the numerical way. It is planned to have a session of TPs (TDs on the computer) of 1h30 for 2 tracks at the end of which there is a digital project to render (the influence of the geometry of the wall on the localization of the eigen modes and dissipation of wave energy). Students will perform modeling, simulation, visualization and rendering of the phenomenon. Office-hours will be organized to help the finalization of the project. To validate the Numerical Analysis track there is a numerical project and to validate the Mathematical Analysis track there is an written exam of 1.5 hours. The Mathematical Analysis track is based on the course handout, which will be made available to everyone. Students of two tracks also have at their disposal all the subjects of the TDs with the corrections. Numerical calculations will be performed on a CentraleSupélec calculation cluster by connecting to Jupyter.

Learning outcomes covered on the course

Theoretical Analysis track:
-understand the theoretical and numerical techniques of acoustic / electromagnetic wave control
-Validate theoretical techniques of acoustic / electromagnetic wave control (shape optimization)
Numerical Analysis track, numerical and algorithmic methods :
- numerical techniques of acoustic / electromagnetic wave control
-Implement numerical methods to simulate acoustic wave propagation phenomena of large dimensions (external / internal problems and problems for a wide band of frequencies)
-Validate numerical techniques of acoustic / electromagnetic wave control

Description of the skills acquired at the end of the course

C1, C2

Theoretical Analysis track (functional analysis, shape optimization):
To be able to deal with the control problems described by the PDEs.
Know how to deal with edge irregularity including fractal to show the well-posed nature of a problem described by PDEs.
Knowing how to apply the method of optimizing shapes and deriving an energy functional from the edge of the domain.
To be able to deduce from the application objectives the constraints of control and the fact of an existence / non-existence of an optimal form.
Target the geometric scales of interest in relation to the wavelengths to be dissipated.
Being able to deal with digital aspects.

Numerical Analysis track (Scientific Computing, numerical and algorithmic methods):

To be able to deal with the control problems described by the PDEs.
To be able to deduce from the application objectives the constraints of control and the importance of an optimal form.
Target the geometric scales of interest in relation to the wavelengths to be dissipated.
Master the finite element method and finite differences and their implementation.
Knowledge of resolution methods related to the simulation of wave propagation.
Mastery of numerical difficulties related to simulation.

2SC5791 – Design of a cladding : Control of external acoustic pollution

Instructors : **Frédéric Magoules**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

We are positioning ourselves on the industrial stakes which impose the economic constraints and the technological constraints necessary for the improvement of the existing products of the market, to design innovative coatings to absorb the noise of the planes, trains, cars. The aim is to develop these innovative products in an optimal way by controlling the energy of the waves by the geometry of the wall while taking into account the economic constraints. For example, COLAS and École Polytechnique have developed an anti-noise wall called "Fractal Wall" TM, which was designed empirically with complex geometry to dissipate different wavelengths. However, this wall even if it is four times more efficient than conventional walls for low frequencies, is almost not sold ... The explanation is that its construction, being by demolding, may break the wall, this which results in a high cost of manufacture. This IS proposes to find by wave control methods optimal forms that are as absorbent as possible (in decibels) that satisfy the constraints imposed by the manufacturer, for example, the least expensive manufacturing cost with the greatest reduction. important decibels. First numerical results in this context show the existence of optimal "not too complex" forms capable of improving the performance of the "Fractal wall" by a factor of 6.

Quarter number

ST5

Prerequisites (in terms of CS courses)

The courses of ST5 and in particular the course "Theory and algorithmics for wave control" (one of two proposed tracks)

Syllabus

Teamwork simulated an "industrial company", definition of issues, bibliographic research, physical understanding and practical interest, mathematical modeling of the problem, development of the corresponding mathematical theory if necessary (the problem well or badly posed, regularity of the solution , derivation of acoustic energy with respect to the geometry of the wall, influence of choice of chosen porous material on the absorption of energy, ...), development / implementation of the numerical method, numerical analysis of the results , the analysis of their relevance, possible improvement, obtaining an effective shape for a large band of frequencies.

Class components (lecture, labs, etc.)

Teamwork, project, dialogue with various specialists in the field.

Grading

Report, final and intermediate deliverables, defense.

Resources

Connection to a cluster at the distance

Students will perform modeling, simulation, visualization and rendering of the chosen phenomenon. They will study the simulation chain with a goal of performance and precision under economic constraints (manufacturing cost) and environmental (gain in decibel or potential).

Deliverables: report, software, transparencies and defense

Learning outcomes covered on the course

Understand the contribution of geometry in the design and development of new products
To understand the theoretical and numerical techniques of acoustic wave control
Implement numerical methods to simulate acoustic wave propagation phenomena of large dimensions (external problems and problems for a wide band of frequencies)
Validate the theoretical and numerical techniques of acoustic wave control
Confront students with the realization of a complex product using numerical simulation techniques

Description of the skills acquired at the end of the course

C4.1 Thinking customer. Identify / analyze the needs, issues and constraints of other stakeholders, including societal and socio-economic: study of industrial, psychoacoustic and environmental interest for the determination of the constraints of the control problem.

C6.1 Identify and use the software necessary for his work on a daily basis (including collaborative work tools). Adapt your "digital behavior" to the context: use and development of a numerical code based on existing parts.

C7.1 Convince on the merits. Be clear about the objectives and the expected results. Be rigorous about the assumptions and the approach. Structure your ideas and your argumentation. Highlight the created value. To convince while working on the relation to the other: by working in team the strategic choice is crucial to have good results of the project, to do it it is necessary to be able to convince the others; teamwork itself; the final defense before a multi-disciplinary jury.

2SC5792 – Design of a cladding : Indoor noise pollution control

Instructors : **Frédéric Magoules**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

We focus on the industrial issues that impose the economic constraints and the technological constraints necessary to improve existing products on the market, in order to design interior coatings to absorb the noise inside the buildings and also acoustic liners in jet engines. In this context we are interested in three key applications: (i) the design of coatings in anechoic chambers (until now acoustic anechoic chambers have been empirically designed based on geometries using different scales), (ii)) the design of perforated absorbent panels (absorbent materials are fibers that have very good acoustic absorbency properties, and are usually covered with wooden panels for aesthetic reasons, which unfortunately hampers their effectiveness) and finally (iii)) absorbent insulations perforated in jet engines. In the last application it is important to optimize the diameter and positioning of the holes in the material. The objectives are to better control the waves by analyzing the optimal shape of the surface of these coatings in order to improve the sound absorption in decibels by taking into account the stakes and industrial constraints.

Quarter number

ST5

Prerequisites (in terms of CS courses)

The courses of ST5 and in particular the course "Theory and algorithmics for wave control" (one of two proposed trackes)

Syllabus

Teamwork simulated an "industrial company", definition of issues, bibliographic research, physical understanding and practical interest, mathematical modeling of the problem, development of the corresponding mathematical theory if necessary (the problem well or badly posed, regularity of the solution , derivation of acoustic energy with respect to the geometry of the wall, influence of choice of chosen porous material on the absorption of energy, ...), development / implementation of the numerical method, numerical analysis of the results , the analysis of their relevance, possible improvement, obtaining an effective shape for a large band of frequencies.

Class components (lecture, labs, etc.)

Teamwork, project, dialogue with various specialists in the field.

Grading

Report, final and intermediate deliverables, defense

Resources

Connection to a cluster at the distance

Students will perform modeling, simulation, visualization and rendering of the chosen phenomenon. They will study the simulation chain with a goal of performance and precision under economic constraints (manufacturing cost) and environmental (gain in decibel or potential).

Deliverables: report, software, transparencies and defense

Learning outcomes covered on the course

Understand the contribution of geometry in the design and development of new products
Apprehend the theoretical and numerical techniques of acoustic wave control
Implement numerical methods to simulate acoustic wave propagation phenomena of large dimensions (internal problems and problems for a wide band of frequencies)
Validate the theoretical and numerical techniques of acoustic wave control
Confront students with the realization of a complex product by numerical simulation techniques

Description of the skills acquired at the end of the course

C4.1 Thinking customer. Identify / analyze the needs, issues and constraints of other stakeholders, including societal and socio-economic: study of industrial, psychoacoustic and environmental interest for the determination of the constraints of the control problem.

C6.1 Identify and use the software necessary for his work on a daily basis (including collaborative work tools). Adapt your "digital behavior" to the context: use and development of a numerical code based on the existing parts.

C7.1 Convince on the merits. Be clear about the objectives and the expected results. Be rigorous about the assumptions and the approach. Structure your ideas and your argumentation. Highlight the created value. To convince while working on the relation to the other: by working in team the strategic choice is crucial to have good results of the project, to do it it is necessary to be able to convince the others; teamwork itself; the final defense before a multi-disciplinary jury.

2SC5793 – Design of a coating : Control of electromagnetic pollution

Instructors : **Anna Rozanova-Pierrat**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

We are positioning ourselves on the industrial stakes which impose the economic constraints and the technological constraints necessary to improve the existing products of the market, this in order to absorb the electromagnetic waves. As fields of application, we aim at the design / optimization of electromagnetic anechoic chambers. It is noted that the absorbent materials (there will be an anechoic chamber visit in the Bréguet building and eventially of Thales-Limours) for the electromagnetic waves are different dissipative materials for acoustic waves.

Quarter number

ST5

Prerequisites (in terms of CS courses)

The course "Engineering of waves" of the 1st year will be a plus.

The courses of ST5 and in particular the course "Theory and algorithmics for wave control" (one of two proposed trackes).

Syllabus

Team work "company", definition of issues, bibliographic research, physical understanding and practical interest, mathematical modeling of the problem, development of the corresponding mathematical theory if necessary (the problem well or badly posed, regularity of the solution , derivation of the electromagnetic energy with respect to the geometry of the wall, influence of the choice of the chosen porous material on the absorption of the energy, ...), development / implementation of the numerical method, the numerical analysis of the results , the analysis of their relevance, possible improvement, obtaining an effective form for a broad band of frequencies.

Class components (lecture, labs, etc.)

Teamwork, project, dialogue with various specialists in the field.

Grading

Report, final and intermediate deliverables, defense by team

Resources

Computer room

Students will perform modeling, simulation, visualization and rendering of the chosen phenomenon. They will study the simulation chain with a goal of performance and precision under economic constraints (manufacturing cost) and environmental (gain in decibel or potential).

Deliverables: report, software, transparencies and defense

Learning outcomes covered on the course

◦ Understand the contribution of geometry in the design and development of new products
◦ Understand the theoretical and numerical techniques of controlling electromagnetic waves
◦ Implement numerical methods to simulate phenomena of propagation of large electromagnetic waves (problems for a wide band of frequencies)
◦ Validate the theoretical and numerical techniques of the control of the electromagnetic waves
◦ Confront students with the realization of a complex product by numerical simulation techniques

Description of the skills acquired at the end of the course

C4, C6, C7

ST5 - 58 - COMPLEX INDUSTRIAL AND CRITICAL SYSTEMS WITH DOMINANTE SOFTWARE

Dominante **:** Info&Num (Computer and Digital)

Langue d'enseignement **:** French

Campus où le cours est proposé **:** Paris-Saclay

Engineering problem

This thematic sequence approaches an axis of software sciences through the implementation of a development cycle allowing the design of complex industrial and critical systems where software is preponderant. Modern industrial systems are often composed of heterogeneous interacting components that can be defined as complex systems (systems of systems). What characterizes such systems is that they are often software dominated (e.g. cyber-physical systems). Moreover, their behavior is often difficult to apprehend because of the emergence of global behaviors that cannot be anticipated at a more local level. Finally, they are critical in the sense that the slightest design error can have crippling consequences on the global behavior of the system.

More precisely, this thematic sequence aims at addressing both the design and the verification of such complex and critical systems by using techniques from Software Engineering. As the components of such systems are heterogeneous (i.e. both physical and software), the methodologies and tools presented in this topic will be multiple and will be integrated in a development cycle. The idea is to start the analysis phase using semi-formal tools (UML, SysML, ...), often used in systems engineering to describe the structuring of the system and its interactions, and then to scientifically approach the design and validation phases using formal techniques of Software Engineering (timed and hybrid modeling, temporal logic, model-checking) The interaction of the system with its external environment (which can be the human user or not) is one of the main points that will be taken into account.

The main objective of such an approach is to show, through the formal models obtained, that the system does what is expected of it while respecting the constraints imposed by the specifications and by the environment, or in the opposite case, to extract the states of the system that may call into question its proper functioning. In the latter case, the economic gain is very interesting and appreciable by the engineers who will benefit from correcting the problems detected by the verification of the model before moving on to the implementation stage (programming).

Adviced prerequisites

None

Context and issue modules:

This part is structured around half-days of training aimed at presenting the sequence, the integration teaching and introducing the theme. Thus, conferences and round tables will be organized on the current state of model-driven engineering in the industrial world and the challenges for the future; or entitled "The application of Formal Methods to Railway Signalling Software".

Specific course (60 HEE) : Design and verification of critical systems

Brief description:

A critical system is a system whose failure can have serious consequences, such as transportation systems (trains, planes, cars ...) or energy production systems (nuclear, wind ...). These systems are complex and in order to guarantee their proper functioning, it is necessary to take into account the continuous and event-driven aspects of their dynamics. A part of the course will therefore be dedicated to the design and modeling of critical and complex systems. In addition, their reliability is a major economic and societal issue. Another part of the course will then be

dedicated to the methods and tools (formal or semi-formal) proposed to guarantee the safety properties during the design phase.

Challenge week n°1: Design of a safe signaling system for railways

Associated partner: ClearSy

Location: Paris-Saclay campus

Brief description:

In a railway system, it is essential that the points do not move when a train runs over them, otherwise there is a high risk of derailing. To this end, a signaling system has signals (a bit like traffic lights on the road) that allow to ask trains to stop before the switches. Things get more complicated if the train is too close to the signal to stop (same problem as an orange light for a car). The objective of this case study is to formally model such a system and to show that it is safe: the trains will not derail.

Challenge week n°2: Design of intelligent systems for automated air traffic control

Associated partner: to be confirmed

Location: Paris-Saclay campus

Brief description:

Critical information systems in the avionics field are subject to very important time and reliability constraints. Their development therefore requires engineering techniques that take these characteristics into account from the early phases of their life cycle. This AR focuses on the design of models of intelligent systems to control air traffic and the verification of certain safety properties on these models. These systems implement many strongly interacting components, which are parallel and asynchronous. All these subsystems are subject to verification and testing to ensure their own functionality. For example, it is critical to demonstrate the absence of deadlocks and the ability of each to operate correctly within their own time constraints. It is also important to schedule the actions of these subsystems and ensure a reliable control of the whole system. As an example, some important properties (formulated in STL) to check: 1) Air traffic should never be allowed in both directions simultaneously on the same route 2) The aircraft must respond to messages within a limited time 3) For two aircraft, there must be a separation with a minimum distance.

Challenge week 3: Signaling Design Automation: from specification to embedded code

Associated partner: Prover

Location: Paris-Saclay campus

Brief description:

The main objective of this study is the development of a railway system using a two-phase approach: The development of a generic application and the Instantiation of this generic application to produce one or more specific applications. The developed approach will be implemented for the development of the interlocking systems of a complete railway line by following the following steps:

– A line is divided into several interlocking stations, generally one per station.

– The same signalling principles are used all along the line.

– Each interlocking station is an instantiation of these general principles.

The study will be finalized by simulating the line by linking the various interlocking stations developed.

2SC5810 – Design and verification of critical systems

Instructors : **Idir Ait Sadoune**
Department : **DÉPARTEMENT INFORMATIQUE**
Language of instruction : **FRENCH**
Type of course : **Specific course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

This course aims to address both the design and verification of complex and critical systems using techniques from Software Engineering. As the components of such systems are heterogeneous (i.e. both continuous for physical and discrete for software), the methodologies and tools presented in this course will be multiple and integrated into a development cycle framework. The idea is to start the analysis phase by using semi-formal tools (UML, SysML,...), often used in systems engineering to describe the structure of the system and its interactions, then to address in a scientific way the design and validation phases using formal techniques of software engineering (timed, stochastic and hybrid modeling, temporal logic, model-checking). The main objective of such an approach is to show, through the formal models obtained, that the system does what is expected of it while respecting the constraints imposed by the specifications and by the environment, or in the opposite case, to extract the states of the system that may call into question its correct functioning. In the latter case, the economic gain is very interesting and appreciable by the engineers who can correct the problems detected by the verification of the model before going to the stage of the implementation (programming).

Quarter number

ST5

Prerequisites (in terms of CS courses)

- Information systems and programming
- Algorithmics and complexity
- Model representations and analysis

Syllabus

1. Chapter 1 - Presentation of temporal logics: LTL, CTL
2. Chapter 2 - Verification with Model Checking
3. Chapter 2 - Timed Automata: Modeling and Verification
4. Chapter 3 - Stochastic Models: Modeling and Verification

Class components (lecture, labs, etc.)

- 10,5h lectures
- 18h tutorials

Grading

Final exam (1H30)

Resources

The contributors (speakers):

- Marc Aiguier, (Department of Computer Science)
- Idir Ait Sadoune, (Department of Computer Science)
- Paolo Ballarini, (Department of Computer Science)
- Lina Ye (Department of Computer Science)

Learning outcomes covered on the course

At the end of this course, the student will be able to:

- Model a critical software system by using different formal approaches (temporal logic, automata, timed automata, stochastic models, hybrid automata).
- Model a critical software system by taking into account different types of constraints (functional, non-functional, temporal, ...)
- Analyze in a scientific way the model of a critical software system using the techniques from Software Engineering (formal verification technique: model checking).
- Extract the states of a critical software system that can call into question its correct functioning.
- Validate the model of a critical software system (the system does what is expected of it).

Description of the skills acquired at the end of the course

- C1 - Analyze, design, and build complex systems with scientific, technological, human, and economic components
- C2 - Develop in-depth skills in an engineering field and a family of professions
- C4 - Have a sense of value creation for his company and his customers
- C6 - Be operational, responsible, and innovative in the digital world
- C7 - Know how to convince

2SC5891 – Design of a safe signaling system for the railways

Instructors : **Idir Ait Sadoune**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The aim is to discover critical systems modeling activities in railway systems, by using the CLEARSY Safety Platform and by proving some safety properties.
During this project, several safety functions will be developed, implemented and improved, mainly using Boolean expressions. Such a system usually has hundreds or thousands of equations, it is understood that this project addresses only a subset of them.
Signaling system control is a risky activity since an error could allow:
- a train derailing.
- two trains colliding.
We will focus on the logical functions that allow a train to make a safe trip for the chosen route topology.

Quarter number

ST5

Prerequisites (in terms of CS courses)

- Design and verification of critical systems (the specific course of the ST)
- Modeling by using B method (to be done at the first day of this ST)

Syllabus

1. - Modeling a critical system by using the B formal method, the Atelier B tool, and the Clearsy Safety platform.
2. - Modeling a railway system.
3. - Modeling and Verification of the safety properties of a railway system.
4. - Generating a source code to be embedded in an electronic card from a B formal model.

Class components (lecture, labs, etc.)

Project over a week (9 half days)

Grading

- Students will be evaluated after a presentation of the obtained results (15 or 20 minutes).

Resources

- Atelier B, a tool enabling the operational use of B method. (https://www.clearsy.com/outils/atelier-b/)
- Clearsy Safety Platform (https://www.clearsy.com/outils/clearsy-safety-platform/).

Learning outcomes covered on the course

Learning outcomes targeted in the course:

- - Modeling a critical system using the B formal method.
- - Modeling Safety properties in the railway systems.
- - Verification of Safety properties by using theorem proving.
- - Generating a source code to be embedded in an electronic card from a B formal model.

Description of the skills acquired at the end of the course

- C1 - Analyze, design, and build complex systems with scientific, technological, human, and economic components
- C2 - Develop in-depth skills in an engineering field and a family of professions
- C4 - Have a sense of value creation for his company and his customers
- C6 - Be operational, responsible, and innovative in the digital world
- C7 - Know how to convince

2SC5893 – Intelligent system for automated control of air traffic

Instructors : **Lina Ye**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Safety-critical systems in the avionics field are subject to strict time and reliability constraints. Their development therefore requires engineering techniques that take these characteristics into account as early as possible in their life cycle. This EI is therefore interested in the design of models of intelligent systems to control air traffic and the verification of important safety properties. These systems are composed of highly interacting components that are parallel and synchronous. All these subsystems are subject to verification to ensure their own functionality. For example, it is essential to demonstrate the absence of deadlock and the possibility for each to ensure correct operations compatible with their own time constraints.

Quarter number

ST5

Prerequisites (in terms of CS courses)

ST5: Industrial complex and critical systems with preponderant software

Syllabus

Based on the informal description of the safety-critical system, the students are asked to use a semi-formal modelling approach to capture and structure safety requirements and then to transform into a formal model (e.g., timed automata) before applying model-checking techniques for the formal verification purposes. An optional part is dedicated to develop a tool to detect a type of unrealistic scenarios in models, which can very often disturb the results of model checkers like UPPAAL.

Class components (lecture, labs, etc.)

One-week project integrating ST5 course content with demonstrative, active and discovery methods.

Grading

report and defense

Course support, bibliography

1. Alur. Alur, R., Dill, D.L. A theory of timed automata. Journal of Theoretical Computer Science 126(2), page: 183–235, 1994
2. Christel Baier and Joost-Pieter Katoen, Principles of Model Checking (Representation and Mind Series). TheMIT Press, 2008.

3. Gerd Behrmann, Alexandre David, Kim Guldstrand Larsen. A Tutorial on Uppaal. Formal Methods for the Design of Real-Time Systems, International School on Formal Methods for the Design ofComputer, Communication and Software Systems, SFM-RT, page:200-236, 2004.
4. Patricia Bouyer, Uli Fahrenberg, Kim Guldstrand Larsen, Nicolas Markey, Joël Ouaknine, James Worrell,Model Checking Real-Time Systems. Handbook ofModel Checking, page:1001-1046, 2018.
5. Patricia Bouyer, François Laroussinie, Nicolas Markey, Joël Ouaknine, James Worrell, Timed Temporal Logics.Models, Algorithms, Logics and Tools, page: 211-230, 2017.
6. Nicolas Navet and Stephan Merz, Modeling and Verification of Real-Time Systems (1st ed.). Wiley-IEEE Press, 2008.

Resources

WIFI,

PROJECTOR,
ELECTRICAL OUTLETS

Learning outcomes covered on the course

Students need to know and understand how to design a safety system with informal and formal approaches by ensuring safety requirements.

Description of the skills acquired at the end of the course

Students must be able to exploit their resources (e.g. their own knowledge), master the work environment, achieve goals by producing results and also develop self-help and sharing with others in the group.

2SC5894 – Automation of signalling design: from specification to embedded code

Instructors : **Idir Ait Sadoune**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The main objective of this study is the development of a railway system using a two-phase approach: The development of a generic application and the Instantiation of this generic application to produce one or more specific applications. The developed approach will be implemented for the development of the interlocking systems of a complete railway line by following the following steps:
– A line is divided into several interlocking stations, generally one per station.
– The same signalling principles are used all along the line.
– Each interlocking station is an instantiation of these general principles.
The study will be finalized by simulating the line by linking the various interlocking stations developed.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Students must have attended the course "Systèmes critiques" of ST5

Syllabus

- Modeling a railway system.
- - Modeling and Verification of the safety properties of a railway system.

Class components (lecture, labs, etc.)

Project over a week (9 half days)

Grading

- Students will be evaluated after a presentation of the obtained results (15 or 20 minutes).

Resources

A tutorial room with WiFi connection

Learning outcomes covered on the course

1. - Modeling a critical system.
2. - Modeling Safety properties in the railway systems.
3. - Verification of Safety properties by using theorem proving.

Description of the skills acquired at the end of the course

- C1 - Analyze, design, and build complex systems with scientific, technological, human, and economic components
- C2 - Develop in-depth skills in an engineering field and a family of professions
- C4 - Have a sense of value creation for his company and his customers
- C6 - Be operational, responsible, and innovative in the digital world
- C7 - Know how to convince

ST5 - 59 - ASSISTANCE AND AUTONOMY OF THE PERSON

Dominante : : : VSE (Living-Health-Environment) and ENE (Energy)

Langue d'enseignement : French

Campus où le cours est proposé : Metz

Engineering problem

This thematic sequence deals with the design of motorized assistance systems for people with reduced mobility, whatever their nature, in its technical, economic and ergonomic aspects. This issue, which has a strong societal impact, is at the heart of two concerns. Firstly, the ageing of the population is increasing the need for this type of system. In addition, due to the evolution of low-cost on-board computer systems, it is now possible to offer increasingly complex functionalities, allowing the spectrum of services provided to be broadened, ranging from motor servoing to more advanced control (trajectory calculation, obstacle avoidance) or even connected and communicating systems.

For example, a very common device nowadays is the wheelchair to help people with reduced mobility (paralysis of the legs). These chairs can be simply mechanical or electrically assisted. Reimbursed by the social security, they are medical devices subject to approval.

Beyond the technical problems, one must also consider the cost (in France the price is fixed by the social security) and the ergonomics. Experiments are taking place on systems that could be different, such as exoskeletons.

Adviced prerequisites: None

Context and issue modules: this part is structured in conferences and round table allowing to apprehend the problematic, the technologies and the stakes of the devices related to the person:

- Environment, type of pathology, manual and electric wheelchairs. Homologation
- How to improve people's lives
- Demonstration of wheelchairs, technological locks, innovation

Specific course (60 HEE): Control of a motorization chain

Short description : This course deals with the notions necessary for the control of a motorization chain in its electronic aspects (converters, power, supply), servo control (modeling, observers, regulators) and digital (analog-digital conversion, programming, real time). The practical aspects will be tested on microcontroller boards in order to implement a speed control system for a DC motor.

Challenge Week : Design of a motorized wheelchair for people with reduced mobility

Associated partner: Logosilver Company, CERAH (Center for Study and Research on the Fitting of the Handicapped)

Location: Metz campus

Brief description : A wheelchair for a person with reduced mobility must ensure a minimum level of safety set by standards. Mechanical design and motor control work together to achieve this safety. The confrontation of the students with the normative and security aspects at the same time as with the mechanical and electronic/computer technical aspects opens them to the multidisciplinary dimension. The specificity of this integration course is the consideration of safety in technical designs. In addition, as current trends are for all objects to be increasingly "connected", functions of this type will be considered (steering the chair from a smartphone, steering the house from the chair, etc.).

This integration course is designed to lead to the concrete realization of a wheelchair. The whole is a mini-project sequenced in individual thematic sessions (mechanics, electronics, computer science, automation...). The themes can be variable according to the groups of students (not all groups do all the themes) and will follow a schedule allowing to arrive at the end at an operational chair.

2SC5910 – Control of a motorization chain

Instructors : **Jean-Louis Gutzwiller**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Specific Course**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

This course covers the necessary concepts to control a motorization chain in its electronic aspects (converters, power, power supply), servo control (modelling, observers, regulators) and digital (analog-digital conversion, programming, real-time). The practical aspects will be tested on microcontroller cards to concretely implement a speed control system of a DC motor.

Quarter number

ST5

Prerequisites (in terms of CS courses)

None

Syllabus

- DC motor
- DC-DC converters
- Mechanical modelling
- Synthesis of control laws (analog regulation and digital regulation)
- Non-linear regulation
- Microcontroller programming

Class components (lecture, labs, etc.)

12h of lecture, 6h of tutorials, 15h of labs and 1h30 for the final exam.

24 students for tutorial/labs groups

Grading

A written report on the practical work, to be given on the date indicated by the teacher, will be requested and a one-and-a-half hour individual exam will take place at the end of the course. The score of the individual examination will count for 60% and the score of the practical work report will count for 40% of the final grade. In case of absence, the standard penalty according to the regulations will be applied.

If the exam fails, a remedial exam will take place in the form of a one-and-a-half hour individual written exam.

Course support, bibliography

« Commande des entraînements à vitesse variable », handout.

Resources

Lectures will be given to present the main concepts.
Applications will be tested on electronic cards during tutorial courses.

Tutorial groups size : 24 students
Lab groups size : 24 students

Learning outcomes covered on the course

- Understanding how motors work
- Choose the characteristics and performances adapted to the problem
- Develop the command laws
- Mastering the servo systems

Description of the skills acquired at the end of the course

- C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components
- C2 : Develop in-depth skills in an engineering field and a family of professions

2SC5990 – Design of a motorised wheelchair for people with reduced mobility

Instructors : **Jean-Louis Gutzwiller**
Department : **DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT, DOMINANTE - ENERGIE**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This integration teaching, which is part of the thematic sequence "Assistance and autonomy of the person", deals with the concepts of how to operate an electric wheelchair for a paralyzed person. Such a chair has a joystick for controlling motors that actuate the wheels. The function of the chair must be as accurate and as fast as possible to respond to the users inputs. The mechanics, the electronics and the algorithms used for the control participate together to obtain the desired performances.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Control of a motorization chain

Syllabus

Different topics will be proposed as:
- study and design of an electronic control board for electrical motors,
- study and design of the computer program to put in the microprocessor,
- study and design of connectivity with other objects (smartphone, internet),
- simulation of the mechanical behavior of the system in order to optimize the control ...

Class components (lecture, labs, etc.)

The students will choose, in groups of 3 to 5, one of the proposed topics. These topics will be dealt with during the project time (from Monday to Thursday) and an evaluation will be done on the last day (Friday).

Grading

Students will be required to provide a written report by group and will have to support their work with an oral presentation. The mark of the report will be 50% in the final mark for all the members of the group and the individual mark obtained at the oral presentation will also be 50% of the final mark.

Resources

Teaching will be in the form of a project during which students will have access to computer, electronic and mechanical equipment (depending on the subject of the project).

Learning outcomes covered on the course

At the end of this course, students will be able to:
- design a part of a motor control chain (depending on the chosen subject),
- pilot the realization of the device (give the manufacturer clear instructions for the realization of the device),
- write and test the computer programs necessary for the operation of the device.

Description of the skills acquired at the end of the course

C4 : Have a sense of value creation for his company and his customers
C6 : Be operational, responsible, and innovative in the digital world
C7 : Know how to convince

ST5 - 60 - SEMI-AUTONOMOUS NAVIGATION OF DRONES

Dominante : : MDS (Mathematics and Data Sciences)

Langue d'enseignement : English

Campus où le cours est proposé : Metz

Engineering problem

Data collection by a human is sometimes extremely difficult, e.g. for exploration/monitoring of abandoned mines or disused buildings, crop monitoring, environmental monitoring. What makes it difficult for a human to explore these areas may depend on the congestion of these areas (e.g. riprap in mines), the accessibility of these areas (e.g. monitoring the state of dykes, river banks ...), the size of the territory to be covered (e.g. monitoring agricultural crops, rivers). In this respect, the recent development of drones offers many opportunities but also raises several problems. To date, the piloting of a drone still requires a certain level of expertise since its control is quite low level. We can then consider a piloting assistance where some aspects of the drone control are managed automatically, due to a processing of the sensors' information flows by machine learning techniques. This semi-autonomous control requires in this case to build from the information of the sensors more integrated representations from which the human, as well as the automatic controller which assists him, can ensure in concert a robust navigation of the UAV.

Adviced prerequisites:

The specific course and the integration teaching require a mastery of several tools (ROS, Linux,...) to which the students will be trained. However, this training to these new tools requires a real motivation and implication of the students. It is also necessary to have skills in Python programming.

Context and issue modules:

This part is structured in conferences and round tables allowing to understand the problems, technologies and stakes related to the use of UAVs in several target areas of the sequence (interventions from Alerion, Parrot, Safran, STEF)

Specific course (60 HEE) : Python programming for robotics

Short description :

This course presents an approach to robotics programming in Python. The first part of the course will cover the basics of Python, including object-oriented programming and system/parallel programming. We will then study in more detail the robotic aspects based on the ROS2 ecosystem. We will implement a visual processing library for navigation that we will deploy on a real robotic platform Turtlebot. All the realizations will be done under Linux with free tools and a part of the labs will allow the students to get familiar with this environment.

Challenge Week : Building inspection by a semi-autonomous drone (quadricopter)

Associated partner: Parrot

Location : Metz campus

Short description :

Students will work on issues related to technical inspection by drones (visual and thermal diagnosis) of hard-to-reach areas of industrial sites, on case studies provided by the industrial partners. They will thus provide answers to their needs in terms of improving energy performance and detecting possible degradations, allowing in particular significant savings at the level of the sites considered.

The students will have implemented servo-control techniques with the particularity of including a human operator in the control loop. They will also have integrated machine learning techniques (vector quantization, supervised learning) on an industrial case, for the interpretation of information flows from sensors (mainly video). This is a first contact with the field of machine learning through the application and experimental side. They will have acquired, through this experience, a more general competence on the design of robotic systems with ROS.

2SC6010 – Python for robotics

Instructors : **Jeremy Fix, Joël Legrand, Herve Frezza-Buet**
Department : **CAMPUS DE METZ**
Language of instruction : **ENGLISH**
Type of course : **Specific course**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

This course presents an approach to robotics programming in Python. The first part of the course will cover the basics of Python, including object-oriented programming and system/parallel programming. We will then study in more detail the robotic aspects based on the ROS2 ecosystem. We will implement a visual processing library for navigation that we will deploy on a real robotic platform Turtlebot. All the realizations will be done under Linux with free tools and a part of the labs will allow the students to get familiar with this environment.

Quarter number

ST5

Prerequisites (in terms of CS courses)

1C1000 : Information systems and programming
1C4000 : Signal processing

Python programming practice is a definitive advantage.

Syllabus

- Labwork (2 x 1h30) introduction to Linux and GIT
- CM (2 x 1h30) : Python object programming course
- Labwork (2 x 1h30) : Object-oriented programming in Python
- Labwork (2 x 1h30) : Efficient vectorized numerical computation with numpy
- Labwork (2 x 1h30) : Multithreaded and multiprocess Python
- CM (1h30) : Introduction to ROS2
- Lab (2 x 1h30): Introduction to ROS2 tutorials
- Lab (4 x 1h30): Line and vanishing point detection for visual servoing of a Turtlebot
- Labwork (2 x 1h30): Semi-autonomous navigation and visuo-guided mapping

Total volume in HPE:
CM: 4.5 HPE
Labwork: 24 HPE

Class components (lecture, labs, etc.)

The course is organized around a few lectures with an important part of practical work. The practical exercises, with real or simulated robotic platforms, will be in particular the occasion to implement and experiment the various concepts seen in the course. This implementation will rely heavily on ROS2. The programming will be done in Python and all the experiments will be done under Linux.

Grading

The assessment will be based on the reports of the practical sessions.

Resources

Teaching team: Joel Legrand, Hervé Frezza-Buet, Jeremy Fix
Software tools: Only free software (Linux, Python, ROS, Gazebo)
Equipment: Turtlebot equipped with LIDAR and 3D camera
Teaching rooms: Teaching room with pre-installed software

Learning outcomes covered on the course

- Structuring computer development using an object-oriented approach in Python
- Write parallel code
- Deploying a robotics platform with ROS2
- Code and deploy a set of ROS2 nodes for a robotic system

Description of the skills acquired at the end of the course

C1 : Analyze, design and implement complex systems with scientific, technological, social and economic dimensions
C2 : Develop broad skills in a scientific or academic field and applied professional areas
C6: Function effectively as an accountable and innovative actor in the digital world

2SC6090 – Building inspection by a semi-autonomous drone (quadricopter)

Instructors : **Jeremy Fix, Joël Legrand, Herve Frezza-Buet**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **ENGLISH**
Type of course : **Challenge week**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The students will work on issues related to the technical inspection of indoor environments by UAVs (visual and thermal diagnosis). They will thus provide answers to needs in terms of improving energy performance and detecting possible damage, in particular allowing significant savings for the considered sites.

During this week of practicals, the focus is on helping a human operator by automating drone control as much as possible and providing the operator with a high level of logical control. The students will have implemented servoing techniques with the particularity of including a human operator in the control loop. They will also have integrated machine learning and pattern recognition techniques for the interpretation of information flows from the embedded sensors (mainly video). This is a first contact, through the application and experimental side, with the field of machine learning.

Through this experience, they will have acquired a more general competence in the design of robotic systems with ROS.

Warning: One of the major achievement of the sequence is the experimental validation on real quadrotors in the corridors and gymnasium of the school. This requires you to master several tools (ROS, Linux, ...) and skills in Python programming. A lot of work and a real motivation are required from the students; The volume of the ST5 and the availability of the teaching staff are reinforced to help you to achieve these goals.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Students should be comfortable with Linux/Ubuntu, ROS and OpenCV. These prerequisites will be taught during the thematic sequence with which this practical is associated.

Syllabus

The practical is divided into three main modules. The first module deals with 1) the low level control loop regulating roll/pitch angles and upward and rotational speeds and 2) some higher level controls (U-turn, translation along an axis). The second module focuses on the management over time of direct behaviors (linear/angular speeds) and logical behaviors (taking the door to the left, moving into the corridor). The third module includes all the image processing functionalities (detection of vanishing lines, calculation of optical flow, etc.). These three modules are further divided with a finer granularity so that the students can parallelize the work.

Class components (lecture, labs, etc.)

- Presentation of case studies by industrial partners
- Designing solutions to proposed problems
- Development of proposed solutions in a real environment
- Implementation on real drones and possible adjustment of solutions
- Presentation/Demonstration of solutions to industrial partners

Grading

Individual and group work will be assessed during the EI period, for competency C6. The oral presentation of each group at the end of the EI on the problem introduced by a company will assess competences C4 and C7.

Resources

Instructor : Hervé Frezza-Buet, Jérémy Fix
Student groups: 5 students
Softwares : Only open source softwares (Linux, Python, ROS, Gazebo-Sphinx)
Hardware: Each group of students will have one bebop2 (lent by Parrot), a joystick, and a laptop
Lab works : The computers in the labs will have all the softwares pre-installed

Learning outcomes covered on the course

- Be able to carry out an ambitious project from start to finish
- Working as a team
- Split the work of a project into subtasks
- Experiment with real robotics platform
- Carry out a software project combining robotics, signal processing and computer science

Description of the skills acquired at the end of the course

C4. Have a sense of value creation for his company and his customers
C6. Be operational, responsible, and innovative in the digital world
C7. Know how to convince

ST5 - 61 - SMART PHOTONICS SYSTEMS FOR CONTROL AND MEASURE

Dominante : : PNT (Physics and NanoTechnology), SCOC (Communicating Systems and Connected Objects)

Langue d'enseignement : English

Campus où le cours est proposé : Metz

Engineering problem

Systems using photonics - science and technology exploiting light - allow to measure, regulate and control physical quantities. These properties of photonic systems are widely used in the regulation of a laser for production systems, in the control of the deflection of a beam to visualize an object or observe the dynamics of biological cells, or in the stabilization of ultra-short pulses in telecommunications. In addition, photonic systems are intelligent systems whose measurements are used to facilitate regulation, for example with the development of telemetry and laser velocimetry - techniques widely used in industrial production and in our vehicles, and essential for the industry of the future and the autonomous vehicle.

Very recently, photonic systems have undergone a revolution in their principle and their use with the development of systems that exploit light at the nanometer and attosecond scales. These innovative systems by their new physics pose important challenges for both the measurement of their physical properties - given the very short spatial and temporal scales - and the exploitation of this measurement for the development of sensors and innovative control systems, given the limitations of our signal processing systems. By studying photonic systems, this thematic sequence will also be an opportunity to learn and master the general notions of analysis, identification and control of non-linear physical systems.

Adviced prerequisites

Basic knowledge of electromagnetism, materials, general electricity and electronics

Context and issue modules:

This part is structured in conferences, round table and visit of the GDI SIMULATION site - Elancourt, in particular around the theme of "laser remote sensing".

Specific course (60 HEE) : Photonics for the control of physical systems

Brief description:

This course will teach the essential concepts of measurement and exploitation of physical quantities of optical electromagnetic waves, in the context of the exploitation of photonics for the observation and control of physical systems. Thus this course will assemble knowledge of:

- Optical measurement and instrumentation: general metrology and error analysis, photometry, and optical detectors, holographic metrology, velocimetry, interferometry.

- Laser source technologies: solid state physics, materials and semiconductors.

- Modeling and control of sources: analysis and non-linear dynamics of laser sources.

- Optical signal generation: techniques for spatial and temporal modulation of optical signals; engineering and design of optical beams.

The concepts covered in the course are :

- Optical metrology

- Photonic technologies including semiconductor materials and optical fibers, phase and intensity modulation

- Signal analysis using the non-linear dynamics of a physical system

- Properties and control of non-linear systems

Challenge Week : Laser remote sensing (LIDAR) for optronic surveillance and target detection

Associated partner: GDI SIMULATION - Elancourt

Location: Metz campus

Brief description :

This EI is based on the use of lasers as tools to control the infinitely small and the ultra fast for, in particular, applications in the field of optronic surveillance and target detection. It is proposed to develop a photonic system whose target application is laser ranging (LIDAR). These lidars have a huge potential for defense, environment, security: identification of mobiles, gas detection, active imaging ... The detection and identification of danger or targets is a key element of defense and security devices, and are key elements for example of the devices developed by GDI SIMULATION for civil aviation or the simulation of laser fire for the training of armed forces. The students will perform the experimental realization of the LIDAR using ARDUINO plat-forms. They will have: i/ to understand the essential physical quantities related to an optical electromagnetic wave ii/ design and realize a servo-driven photonic system iii/ engineer and control innovative optical beams by exploiting spatial and temporal signal modulation techniques v/ make a choice of devices to answer an economic problem of sizing and energy consumption.

Recent advances in the realization of innovative optical beams will also allow the exploration of new beam topologies (e.g. Airy beams: non-diffracting, curvilinear trajectory, self-regenerating in case of obstacles) which open the way to improved performances (spatial resolution, speed, etc.).

2SC6110 – Photonics for the control of physical systems

Instructors : **Nicolas Marsal**
Department : **CAMPUS DE METZ**
Language of instruction : **ENGLISH**
Type of course : **Specific Course**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

This course will teach the basic knowledges of the measurement and exploitation of the physical quantities of optical electromagnetic waves, in the context of the exploitation of photonics for the observation and control of physical systems.
It will focus on:

- Optical metrology
- Photonic technologies including semiconductor materials and optical fibers, phase and intensity modulation
- Signal analysis exploiting in particular the non-linear dynamics of a physical system
- Properties and regulation of non-linear systems

Quarter number

ST5

Prerequisites (in terms of CS courses)

Basic knowledge of electromagnetism, materials, electricity and electronics.

Syllabus

1. Optical measurement and instrumentation: generalities in metrology and error analysis, photometry, and optical detectors, holographic metrology, velocimetry, interferometry.
2. Laser source technologies: additions to solid state physics, materials and semiconductors.
3. Modeling and control of sources: analysis and non-linear dynamics of laser sources.
4. Generation of optical signals: spatial and temporal modulation techniques of optical signals; engineering and optical beam design.

Class components (lecture, labs, etc.)

30h00 lectures and 3h00 practical exercices

Grading

Oral exam by group of 3-4 students. 15 minutes of presentation on a peculiar photonic topic.

Resources

Lecturers: Nicolas Marsal, Delphine Wolfersberger, Marc Sciamanna

Learning outcomes covered on the course

Thanks to this course, students will learn the physical quantities and tools which allow to spatially characterize optical beams, to analyze their frequencies, to modulate their intensities, their phases to guide them in different physical systems (fiber, waveguide ...)
They will see the linear and non-linear dynamics associated with those beams when they propagate in different materials and / or physical systems.
Thanks to this course and in addition to the EI, the student will be able to physically design a LIDAR, to test its performance and to compare it with other equipment used in optical metrology.

Description of the skills acquired at the end of the course

C1 Analyze, design,and buildcomplex systems with scientific, technological, human, and economic components
C2 Develop in-depth skills in an engineering field and a family of professions

2SC6190 – Laser remote sensing (LIDAR) for optronic surveillance and target detection

Instructors : **Delphine Wolfersberger**
Department : **DOMINANTE - PHYSIQUE ET NANOTECHNOLOGIES**
Language of instruction : **ENGLISH**
Type of course : **Challenge week**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This EI is based on the use of lasers as tools to control the infinitely small and the ultra-fast for, in particular, applications in the field of optronic surveillance and target detection. It is proposed to develop an innovative control-command solution for the generation of ultrashort laser pulses and the implementation of a photonic system whose intended application is laser telemetry (LIDAR: laser radar). These "lidars" have enormous potential for defense, the environment, security: mobile identification, gas detection, active imaging, ... The detection and identification of danger or targets is a key element of the defense and security systems , and are key elements for example devices developed by GDI Simulation for civil aviation or simulation of laser shooting for the training of the armed forces.

Quarter number

ST5

Prerequisites (in terms of CS courses)

None

Syllabus

The students will be divided into different groups each performing 4 practical works.
Practical Work Proposal:
1 / a session on the emitting laser: realization and characterization of a laser transmitter regulated in temperature so as to maintain its constant power
2 / a session on the generation of a laser pulse: study of the generation of a laser pulse via the use of an optical feedback loop
3 / a session on the shaping of the laser beam: shaping of the laser beam via the appropriate optics and / or via the use of a spatial light modulator (SLM) allowing ultimately the use of beams not Conventional (ex bundles of Airy)
4 / a session on the receiver: development of the device for receiving and analyzing the optical signal
These 4 sessions will be followed by a session on the synthesis of the different experiments for the realization of a telemetry device and possibly the development of the servo system necessary for the laser signal to reach the target.

Class components (lecture, labs, etc.)

Experimental and digital realization in team in the form of a challenge

Grading

Oral presentation in front of CS professors and industrial partner GDI Simulation

Resources

optical set-ups
Pedagogical Team : Delphine Wolfersberger - Nicolas Marsal

Learning outcomes covered on the course

The students will perform the experimental realization of the LIDAR using ARDUINO plat-forms. They will have:

i/ to understand the essential physical quantities related to an optical electromagnetic wave

ii/ design and realize a servo-driven photonic system

iii/ engineer and control innovative optical beams by exploiting spatial and temporal signal modulation techniques

iv/ make a choice of devices to answer an economic problem of sizing and energy consumption.

Recent advances in the realization of innovative optical beams will also allow the exploration of new beam topologies (e.g. Airy beams: non-diffracting, curvilinear trajectory, self-regenerating in case of obstacles) which open the way to improved performances (spatial resolution, speed, etc.).

Description of the skills acquired at the end of the course

C4 Have a sense of value creation for his company and his customers
C6 Be operational, responsible, and innovative in the digital world
C7 Know how to convince

ST5 - 62 - INTELLIGENCE ENERGETIQUE ET SMART BUILDING

Dominante **: GSI (Large Interacting Systems) and SCOC (Communicating Systems and Connected Objects)**

Langue d'enseignement **: French** with specific modalities to allow the adaptation of students with a low level in French: all the materials are in English, the tutorials, the practical work as well as the integration teaching are provided in English. Support sessions in English are also scheduled.

Campus où le cours est proposé **: Rennes**

Engineering problem

Buildings must no longer be considered as simple consumers, but as true energy players, fully integrated into their ecosystems, and must be fully integrated into a renewed vision of society, where comfort and health are in harmony with energy management. To do this, we need to rethink the systems that make up the building, through new control functions and stronger interactions with the occupants. The "building" ecosystem is complex, because it is made up of a heterogeneous set of systems: local production, storage, supply, sale, and the various equipment, which must be coordinated for optimized management.

The engineer's challenges are first to analyze the needs and to specify the intelligent control systems. This design is based on the integration of control algorithms deployed on communicating systems to achieve an optimal compromise between technology - cost - efficiency, such as closed-loop performance, communication frequency and protocol, sensor autonomy and actuator lifetime.

Adviced prerequisites: None

Context and issue modules :

This part is organized around several conferences that should give students the keys to understanding the major issues associated with this thematic sequence. Starting with the industrial issues: what are the needs of today and tomorrow, in terms of services and technologies: challenges and scientific obstacles. Then presentation of the difficulties encountered for the capture of heterogeneous data from which we can perform analyses and exploit these data.

Knowledge contributions will be given to understand the needs and the heterogeneity to be taken into account for the management of comforts (air quality, thermal comfort, ...). Finally, a last intervention will present the "Research" point of view around intelligent buildings.

Specific course (60 HEE) : Students will be required to choose from one of the following two specific courses:

Option 1: Energy-efficient communications

Brief description:

With a global electricity consumption of 6 to 10% corresponding to 4% of greenhouse gas emissions, ICST (Information and Communication Sciences and Technologies) must rethink the way they transmit, process and store data. The arrival of 5G (5th Generation mobile) and the explosion of connected objects (Internet of Things) suggest that the sector will continue to grow strongly in the coming years, making it all the more urgent to offer more environmentally friendly communications. The need for spectral efficiency (transmitting a given data rate in a given bandwidth) must then be combined with a strong energy efficiency constraint (transmitting while consuming as little as possible). This course provides training in digital communication concepts and tools for which energy efficiency is explicitly taken into account.

Option 2: System architecture and modeling

Brief description:

Today's systems are increasingly complex. This complexity comes from the complexity of their structure and the interactions between the different components, the increase and the complexity of the exchanged data, the heterogeneity of concepts, substances, trades, standards, but also the human complexity (organization, ergonomics, psychology, sociology...). In order to better control this complexity, it is often necessary to rely on a modeling of the different artifacts of the system. This modeling allows, at different phases of the system's life, to better understand the needs it must meet, to structure its architecture, to make analyses in order to predict its behavior and thus to make a justified choice between several solutions. The different models constitute a common reference for the different parties involved in the design of the system. The objective of this course is to train students to model and structure a system architecture. Technological systems will be privileged with domains such as avionics, railways, industry, health, energy etc. Emphasis will also be placed on the ability to identify the characteristic performance attributes essential in the design, implementation, operation and management of complex systems.

Challenge Week 1: Hierarchical management of thermal comfort

Associated partner: Delta Dore (to be confirmed)

Location: Rennes campus

Brief description :

The objective is to define a modular system, allowing the implementation of hierarchical control strategies between a local regulation of comfort per zone and a supervisor managing the intermittence of the occupation, the limitation of available power in order to minimize the consumption related to thermal comfort. The challenges induced by this project are the consideration of societal issues (human, comfort and energy efficiency), technical constraints (power limitation, ease of implementation and robustness of the solution) and the technologies allowing the implementation. The different groups will have to collaborate to address the different aspects of the project and to achieve a proof of concept.

Challenge Week 2: Remote control of thermal comfort

Associated partner: Delta Dore (to be confirmed)

Location: Rennes campus

Brief description :

In the context of thermal renovation, remote control solutions are often much more straightforward to deploy than solutions that require running new cables through the walls. The objective of this integration course is to realize the whole remote control system for the heating of several rooms. This realization requires the actual implementation of the communication system between the controller and the heating devices. Groups will compete to find the most relevant technological solution while integrating economic and ecological dimensions.

2SC6210 – High energy performance communications

Instructors : **Yves Louet**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Specific course**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

ICT (Information and Communication Technologies including base stations, data centers, user equipment's, etc.) field is responsible of 6 to 10% of the worldwide electrical consumption what corresponds to 4% of the greenhouse gases emissions. With an early growth of 7% especially with the coming 5G and the expected increase of billions of connected "things", it is urgent to reduce this footprint by finding new ways of transmitting, processing and saving data. That is to say spectral efficiency (ie transmit the maximum data in a given bandwidth) have to be joined with the objectives to increasing the energy efficiency of the links. To do so the milestones of this courses are:

- Make the audience aware of the ICT footprint

1. Explain with is power consuming in ICT and where are the potential gains

- Draw the communications chain (transmitter, channel, receiver) with the key parameters which come into play (bandwidth, data bit rate, power, link budget, etc.). Explain the role of the key components (coding, modulation, filtering, etc.).
- Put in light one of the most dimensional factor : constant or no-constant envelope signal Continuous Phase Modulation (CPM) modulation format with constant envelope (MSK, GMSK, FSK, OQPSK, ….) and their associated receivers
- The associated standards (mobile communications, Bluetooth, IoT, aeronautical communications, etc.).
- compare the linear and non linear modulations

Quarter number

ST5

Prerequisites (in terms of CS courses)

Most of the prerequisites of this course fit with the topics covered in the 1A course entitled "Signal Processing" (1CC4000). In particular :

- deterministic modelisation of signals
- power, energy, correlation
- Fourier transform and spectral representation of signals
- spectral analysis
- filtering and convolution
- sampling of signals and aliasing
- Discrete Fourier Transform

Syllabus

1. Introduction : ICT footprint

a. The networks
b. The user equipment's

2. Linear modulations

a. Bit to symbol coding
b. Symbol to signal coding : waveform filtering : intersymbol interferences
c. Spectrum density
d. Examples of standards

3. Linear modulations

a. CPM (FSK, MSK, GMSK, OQPSK, etc.)
b. Receivers architectures
c. Examples of standards

4. Comparison between linear / non linear modulations

a. Spectrum sefficiency
b. Energy efficiency
c. Bit error rate performance on AWGN channel

Class components (lecture, labs, etc.)

Regarding the HPE (Heures Présentiel Elèves), the course is divided into three part:

- 16,5 hours of lectures
- 4,5 hours of tutorials classes
- 12 hours of laboratory classes

Furthermore, 25,5 hours of personnal works are scheduled. This course will be evaluated by a 1,5 hour exam and by the reports of laboratories classes. The Professors are Yves Louët (head of the course) and Haïfa Fares.

All lectures will be given in french with specificities for students who have a low level in french : all documents will be in english and tutorial classes, laboratory classes and the "enseignement d'intégration" could be given in english. Additional hours as tutoring in english will be scheduled.

Grading

This course will be evaluated by :a score related to laboratory classes reports (weighted 0.2) and a score of a 1h30 exam duration (weighted 0.8)

Competencies 1 and 2 will be evaluated in the introduction (stakes and context) and in the specific course
Competencies 4, 6 and 7 will be evaluated during the final defense related to the integrated courses.

Course support, bibliography

[1] J. B. Anderson, T. Aulin, and C.-E. Sundberg, Digital Phase Modulation. New York: Plenum Press, 1986.
[2] L. H. J. Lampe, R. Tzschoppe, J. B. Huber, and R. Schober, "Noncoherent Continuous- Phase Modulation for DS-CDMA," in Communications, 2003. ICC '03. IEEE International Conference on, vol. 5, pp. 3282–3286 vol.5, May 2003.
[3] M. Mouly and M.-B. Pautet, The GSM System for Mobile Comm.. Telecom Publishing, 1992.
[4] M. K. Simon, Bandwidth-Efficient Digital Modulation with Application to Deep-SpaceCommunications. John

Wiley & Sons, 2005.
[5] Reducing the Energy Consumption of Photonics Hardware in Data Center Networks Authors: Richard Penty, Jonathan Ingham, Adrian Wonfor, Kai Wang, Ian White Richard Penty, Core Switching and Routing Working Group Adrian Wonfor, Green Touch, 2012

Resources

Regarding the HPE (Heures Présentiel Elèves), the course is divided into three part:

- 16,5 hours of lectures
- 4,5 hours of tutorials classes
- 12 hours of laboratory classes

Furthermore, 25,5 hours of personnal works are scheduled. This course will be evaluated by a 1,5 hour exam and by the reports of laboratories classes. The Professors are Yves Louët (head of the course) and Haïfa Fares.

Learning outcomes covered on the course

At the end of this course, the student will be able to:

- evaluate the carbon footprint of the ICT (Information and Communication Technology) domain
- identify the most energy consuming processings and devices to transmit information
- argue about the most appropriate choice of parameters for a transmission according to the needs
- simulate a high energy efficiency radio transmission and establish its performance
- evaluate the trade-off between spectral efficiency (for high bit rate) and energy efficiency (energy saving) for a given transmission
- justify the use of high energy efficiency waveforms in some contexts (Internet of Things, low bit rate transmissions, autonomy, ...)

Description of the skills acquired at the end of the course

C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 : Develop in-depth skills in an engineering field and a family of professions
C4 : Have a sense of value creation for his caompany and his customers
C6 : Be operational, responsible, and innovative in the digital world
C7 : Know how to convince

2SC6291 – Hierarchical management of thermal comfort

Instructors : **Herve Gueguen, Romain Bourdais**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **ENGLISH**
Type of course : **Challenge week**
Campus : **Rennes**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The building must no longer be considered as a simple consumer but as a real energy actor perfectly integrated into its ecosystem. It must be fully integrated into a renewed vision of society, where comfort and health are in harmony with energy management. This requires rethinking the systems through new steering functions and stronger interactions with occupants. The "building" ecosystem is complex, because it consists of a heterogeneous set of systems: local production, storage, supply, sale, and the various equipment, which must be coordinated for optimized management.
The challenges facing the engineers are first the analysis of needs and the specification of intelligent control systems. This design is based on the integration of control algorithms deployed on communicating systems to achieve an optimal compromise between technology - cost - efficiency, such as closed loop performance, communication frequency and protocol, sensor autonomy and actuator life.

The objective is to define a modular system, allowing to implement hierarchical control strategies between a local regulation of comfort by zone and a supervisor managing the intermittency of the occupation, the limitation of available power in order to minimize the consumption related to thermal comfort. The challenges induced by this project are the consideration of societal issues (human, comfort and energy efficiency), technical constraints (power limitation, ease of implementation and robustness of the solution) and technologies allowing implementation. The different groups will have to work together to address the different aspects of the project and result in a proof of concept implementation.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Control theory (commun course 2A)

The course System Architecture and Modeling

Syllabus

This course is built from a simulator/emulator of the thermal behaviour of a building, whose meteorological data and conditions of use are taken from data from the city of Rennes.

The energy manager that the students will have to build will have to be implemented and validated in the simulator.

Class components (lecture, labs, etc.)

The pedagogical activity alternates between working together and working in mini-groups to arrive at a collective proposal at the end of the week. The courses are in French with specific modalities to allow the adaptation of students with a low level in French: all the materials are in English, the tutorials, the practical work as well as the integration teaching are provided in English. English support sessions are also scheduled.

Grading

The activity will be evaluated during the various daily points and during the final presentation.

Resources

A building thermal simulator is made available to the students. They will then be able to work in groups on the project, taking advantage of the supervision of 2 research professors of the school with complementary skills (system modeling and automation)

Learning outcomes covered on the course

At the end of this teaching, the students will be able to:
- implement a collaborative control strategy
- simulate the behavior of the building and evaluate the relevance of the proposed solution
- present a technological solution and valorize it from a technical-economic point of view

Description of the skills acquired at the end of the course

C4.1 : Identify and (re) formulate the customer's need to create value and the associated challenges or constraints. Identify and integrate other stakeholders, internal and external, and other dimensions not mentioned initially (technical, economic, human, etc.)
C6.2 : Design software
C7.1 : Basically: Structure ideas and arguments, be synthetic (assumptions, objectives, expected results, approach, and value created)

2SC6292 – Remote control of thermal comfort

Instructors : **Haïfa Jridi**
Department : **DOMINANTE - GRANDS SYSTÈMES EN INTERACTION, DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **ENGLISH**
Type of course : **Challenge week**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This teaching aims to use the knowledge achieved through the courses of the ST "Energy intelligence and intelligent buildings" to design an automatic remote control system of thermal comfort in a multi-zone space therefore with different considerations and resources.

Quarter number

ST5

Prerequisites (in terms of CS courses)

- High energy-efficient communications
- Energy intelligence and smart buildings

Class components (lecture, labs, etc.)

- Teamwork (brainstorming)
- Harmonization of tasks and tools used:

* Simulink for simulations

* GNU-Radio for real transmission emulation

- Definition of needs and performance indicators
- preparation of deliverables

Grading

The final mark includes an evaluation of the individual contribution (work in subgroups and involvement) and a collective evaluation (deliverables, intermediate technical validations, final presentation). A penalty of - 2 pts is applied per half-day of absence not justified

Resources

- Teaching team for supervision: Romain Bourdais and Haïfa Farès.
- Software tools: MatLab and GNU-Radio for simulations
- Hardware tools: USRP modules for real transmissions to be configured using GNU-Radio.
- Lab rooms

Learning outcomes covered on the course

- Design a multi-zone thermal comfort regulation system that works remotely
- Introduction to Software Defined Radio
- Realization of the wireless communication between the building and the controller
- Considerations on the trade-off between the use of the wireless communication protocol and the quality of service of the control

Description of the skills acquired at the end of the course

Skills developed: C1.4, C4.2, C6.1 and C7.1.

ST5 - 63 - SMART AND EMBEDDED SYSTEMS FOR HEALTH

Dominante **:** GSI (Grands Systèmes en Interaction), VSE (Vivant-Santé-Environnement) et SCOC (Systèmes Communicants et Objets Connectés)

Langue d'enseignement **:** French with specific modalities to allow the adaptation of students with a low level in French: most course materials are in English and the integration teaching is provided in both English and French.

Campus où le cours est proposé **:** Rennes

Engineering Problem

Technological advances in terms of the measuring elements miniaturization and the control of physiological quantities allow new solutions for patient care: substitution for the control of defective organs, continuous, automated, and patient-adapted delivery of treatments. On the other hand, integrating digital communication capabilities between these control elements and connected everyday objects (smartphones, tablets, etc.) opens new opportunities for better patient involvement and doctor monitoring.
The societal stakes are apparent, both in terms of improved health and daily comfort for the patient and reduced risk of severe pathologies in the longer term.
For the engineer, the challenge is to offer a reliable integrated solution that is easy to use and adjust, low in energy consumption, and easily adaptable to a wide variety of patients.

Prerequisites None

Context and challenges modules:

This part is organized around several lectures that should give the students the keys to understand the significant issues associated with this thematic sequence. The following aspects will be addressed: the medical aspects of diabetes treatment, the problem of embedded for health, the ethical, social and human aspects through the influence of connected objects, the security of personal data, the impact of antennas.

Specific course (60 HEE,FR): Energy-efficient communications

Short description:

With a global electricity consumption of 6 to 10%, corresponding to 4% of greenhouse gas emissions, ICST (Information and Communications Sciences and Technologies) must rethink how they transmit, process, and store data. The arrival of 5G (5th Generation mobiles) and the explosion of connected objects (Internet of Things) suggest that the sector will continue to grow very strongly in the next years, making it more urgent to offer more environment-respectful communications. Spectral efficiency requirements (transmitting a rate within a given bandwidth) must then be combined with an intense energy efficiency constraint (transmitting while consuming as little as possible). This course provides training in digital communication concepts and tools for which energy efficiency is explicitly taken into account.

Specific course (60 HEE,EN): System Architecure and Modeling

Short description:

Modern systems are becoming more and more complex. This complexity results from the interaction between their components, the increase and complexity of the exchanged data, the heterogeneity of concepts, substances, trades, standards, but also from human complexity (organization,ergonomics, psychology, sociology ...). To better handle this complexity, it is often necessary to model the different artifacts of the system. This modeling allows

stakeholders at different phases of the system's life to better understand its objectives, to structure its architecture, to make analyses to predict its behavior, and thus to make a justified choice between alternatives. The various models constitute a reference for all stakeholders involved in the system design. Thus, the objective of this course is to provide students techniques and tools for modeling and structuring system architectures. Technological systems will be privileged with fields such as avionics, railway, industry, energy, or health. Moreover, the emphasis will be made in identifying system performance attributes (critical SPI system performance indicators) that need to be monitored to design, implement, operate, or manage complex systems.

Challenge week : Smart system for personalized blood glucose control

Associated partner: CHU Rennes – Diabetology Department.

Location: Campus of Rennes

Short description:

The objective is to propose a system to help regulate blood sugar levels for diabetic patients. This system must respond to various issues: operational safety and comfort of use for the patient, digital integration of control algorithms, ability to interact with control elements (subcutaneous blood glucose sensor, micro-pump for insulin delivery, ...) via various communication protocols and low energy cost. It must allow local interaction with the patient and remote interaction with a doctor to monitor biomedical data.

2SC6310 – System Architecture and Modeling

Instructors : **Herve Gueguen, Nabil Sadou**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Specific course**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

Modern systems are becoming more and more complex. This complexity results from the interaction between their components, the increase and complexity of the exchanged data, the heterogeneity of concepts, substances, trades, standards, but also from human complexity (organization, ergonomics, psychology, sociology ...).
To better handle this complexity, it is often necessary to model the different artifacts of the system. This modeling allows stakeholders at different phases of the system's life to better understand its objectives, to structure its architecture, to make analyses to predict its behavior, and thus to make a justified choice between alternatives. The various models constitute a reference for all stakeholders involved in the system design.
Thus, the objective of this course is to provide students techniques and tools for modeling and structuring system architectures. Technological systems will be privileged with fields such as avionics, railway, industry, energy, or health. Moreover, the emphasis will be made in identifying system performance attributes (critical SPI system performance indicators) that need to be monitored to design, implement, operate, or manage complex systems.

Quarter number

ST5

Prerequisites (in terms of CS courses)

none

Syllabus

1. Introduction to system modeling
2. Stakeholders' needs and requirements modeling
3. System architecture structuring and modeling
4. Behavioral modeling and composition
5. Choice of structure
6. Technical solutions modeling and trade-off

Class components (lecture, labs, etc.)

The courses are in French **with specific modalities to allow the adaptation of students with a low level in French:** all the materials are in English, the tutorials, the project are provided in English. English specific sessions are also scheduled.

Grading

written exam (1h) (30%) and regular testing (70%)

Resources

lectures, exercises, case study

Learning outcomes covered on the course

By the end of this course, students will be able to :
- Design and implement system modeling (Observe, Define the system, Propose a formal model, Analyze and Exploit the results)
- Understand the concepts of system structure (components, hierarchies, and decomposition principles) with a particular focus on the interactions between the elements of a system (causal or non-causal, synchronous, or asynchronous, information or energy exchange interfaces, etc.).
- Understand and analyze interactions to accurately organize the architecture of a system to facilitate its modularity and future evolutions.
- Deploying the various techniques of behavioral modeling of a system to predict its behavior.

Description of the skills acquired at the end of the course

- C1.1Examine a problem in full breadth and depth, within and beyond its immediate parameters, thus understanding it as a whole. This whole weaves the scientific, economic, and social dimensions of the problem.
    - C1.1 Study a problem as a whole, the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human dimensions
    - C1.2Select, use, and develop modeling scales, allowing for appropriate simplifying hypotheses to be formulated and applied towards tackling a problem.
- C8 Leading a project, a team

a. C8.1 Work collaboratively in a team.

2SC6390 – Smart system for personalized blood glucose control

Instructors : **Marie-Anne Lefebvre**
Department : **DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT, DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The objective is to offer a blood glucose regulation support system for diabetic patients;

This system must address various issues: operational safety and ease of use for the patient, digital integration of control algorithms, ability to interact with control elements (subcutaneous blood glucose sensor, micro insulin delivery pump,...) via various communication protocols and low energy cost;

It must allow local interaction with the patient and remote interaction with a doctor for the monitoring of biomedical data.

Quarter number

ST5

Prerequisites (in terms of CS courses)

Modeling
Information systems and programming

Syllabus

Understanding the issue
Definition of requirements (safety, comfort,...)
Definition of the functional and physical architecture of the control system
Modeling and study of a corrector
Study of the embedded integration of the corrector
Study of the aspects : patient interface and communication with the embedded controller
Integration and Validation
Synthesis

Class components (lecture, labs, etc.)

Work in groups of 5-6 students

Grading

Summary notes, Final defense and demonstration

Learning outcomes covered on the course

Students will be able to:
- Apply the principles of a system analysis methodology
- analyze and carry out the integration of a real time regulation
- have programming bases for the sofware components dedicated to embedded systems, and for their inter-communication

Description of the skills acquired at the end of the course

C1 Analyse, design, and build complex systems with scientific, technological, human, and economic components
C2 Develp in-depth skills in an engineering field and a family of professions
C4 Have a sense of value creation for his company and his customers
C6 Be operational, responsive, and innovative in the digital world
C7 Know how to convince

ST5 - 64 - MODELING AND DEVELOPMENT OF SUPERVISION SOFTWARE

Dominante **:** Info&Num (Computer Science and Numerics) and SCOC (Communicating Systems and Connected Objects)

Langue d'enseignement **:** French

Campus où le cours est proposé : Rennes

Engineering problem

Today, IT is ubiquitous, and in particular enables the supervision of sensors and connected objects, as well as the processing and analysis of the data they generate. For example, in the medical field, connected insulin pumps or pacemakers can be used to collect data for historical and statistical purposes on groups of individuals. In the "smart building" context, information systems can, for example, be used to control or bill buildings.

The aim of such a supervision system is to provide users and supervisors with aggregated information, but also to regulate the system by sending control commands to sensors and connected objects. Thus, the software implementation of such a system relies on multiple services, with multiple users manipulating data specific to their role. The difficulty of such an implementation lies not only in the modeling and volume of data processed in real time, but also in the choice and definition of the software architecture that will deliver an efficient system while ensuring easy maintainability.

In this ST, we propose to study the design of such a system. To this end, we will study data modeling and management, as well as design patterns that will accelerate development while facilitating system maintainability. In addition, the integration course will illustrate the benefits of an AGILE organization, enabling us to design a functional system as early as possible, and to make it evolve in line with customer requirements.

Adviced prerequisites

None

Context and issue modules:

The context and issues modules of this thematic sequence are based on those of the two other thematic sequence topics offered on the Rennes campus, "Health" and "Smart Building". The first 2 workshops are therefore "shared" with these other thematic sequences. This is followed by workshops specific to software development. Subjects covered include embedded development, Lora networks and UML modeling, depending on industry availability. Practical refresher workshops on basic software development tools (git, command line, etc.) complement the lectures given.

Specific course (60 HEE) : Data models and design patterns

Brief description: This course introduces the concepts needed to design software that handles large quantities of data. It introduces object-oriented programming through two languages, Java and Kotlin. It then moves on to software engineering methodologies, in close connection with the system modeling course, in which the various diagrams (class, sequence, etc.) are discussed. The course enables students to question the relevance of software code structuring with regard to existing design patterns. To this end, tutorials based on the system modeling course, which runs in parallel, will be carried out using inverted pedagogy.

The second part of the course focuses on data storage and manipulation. It will cover the fundamentals of database software and the theoretical issues involved (formatting, queries). Finally, this section concludes with an introduction to object-relationship mapping software, which enables data to be linked with the application's business code, and which requires special modeling skills.

Challenge Week n°1 : Development of a sensor supervision system

Associated partner: None directly, but some in partnership with ST5 Intelligent and Embedded Systems for Healthcare and equipment deployed in the Smart and Secure Room.

Location: Rennes campus

Brief description: In collaboration with students from the Rennes campus "Intelligent and Embedded Systems for Health" thematic sequence, or from the Smart and Secure Room, the aim is to develop the information system that will collect and process data from sensors, and provide services to regulate them. The pedagogical objective is to discover the specificities of development in the Cloud and to perceive the interest of design choices to facilitate software evolution, as well as the benefits of an AGILE organization.

2SC6410 – Data models and design schemas

Instructors : **Jean-Francois Lalande**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Specific course**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

This course allows to discover the necessary notions for building software that manipulate large quantities of data. It learns the object oriented programming using two languages, Java and Kotlin. It then present the methologie of software design with a link with the course of system modeling that introduce the different activity diagrams (activities, sequence, blocks, etc.). The course helps students to wonder about the structure of software when using different design patterns. For this, the labs that are based on the course of system modelling that occurs in parallel will be realized in inversed pedagogy.

In a second part, the course forcuses on the data manpulation. The goal is to learn the basic about database software and the theoritical problems behing them (data structuration, requests). Finally, this part is concluded with a presentation of software that helps to implement object-relation mapping.

Quarter number

ST5

Prerequisites (in terms of CS courses)

- Information System and Programming
- Algorithms and complexity

Syllabus

Object oriented programming (Java/Kotlin)

1. Inheritance, encapsulation, polymorphism, dynamic dispatch
2. Generiity, covariance, contravariance, invariance
3. Fonctions and anonymous classes
4. Types and type inference

Lab: discovering of the languages and illustrating the course notions
Personal work: go further with reflexivity, serialisation, Java NIO, JNI, Garbage collector

Software engineering

- Historical methods: V cycle, spiral circle, tests
- UML diagrams: using diagrams seen in "System Models" (use case, sequence, classes, state transition)
- Test and continuous integration

Relational databases

- Relational algebra
- Database design, normalization
- SQL language, requests, indexing
- Optimizing requests

Introduction to design patterns

Personal work: finish the lab on oriented programming + databases + software engineering

Class components (lecture, labs, etc.)

33.5 HPE: 12h of course, 3h of exercices, 18h of practical labs, 1,5 Exam

Grading

Final exam: 1h30 : 50 % Continuous control: TL software engineering, by pairs of students: 15 min of presentation, 10 minutes of questions : 50%. In case of a justified absence to one of the intermediary examinations, the grade of this latter is replaced by the grade of the final examination.

Resources

Computer labs;

- Eclipse, IntelliJ
- Database software

Learning outcomes covered on the course

- Do object oriented programming
- Choose correctly the adequate design patterns
- Know how to manipulate data in a database
- Modelise with an object-relation mapping

Description of the skills acquired at the end of the course

C1.2 Use and develop adapted models, chose the righ model scale and the hypothesis for tackle the problem
Evaluated by a written exam.

C2.2 Transfer knowledge and methodology across multiple disciplinary fields.
Validated by the introduction of the ST5 (Quizz).

C6.2 Specify, develop, and validate a complex software
Evaluated by a lab for designing a library.

2SC6490 – Development of a sensor monitoring system

Instructors : **Jean-Francois Lalande**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS, DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRENCH**
Type of course : **Challenge week**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In partnership with other students of the campus following the thematic sequences "Health" and the equipments of the Smart and Secure Room, the objective is to develop the information system that will enable the collection and processing of data from sensors, and to provide services for the regulation. The educational objective is to perceive the specificities of the development of applications in the cloud et to discover the interest of design choices to facilitate the software evolution, and the benefits of an AGILE organization.

Quarter number

ST5

Prerequisites (in terms of CS courses)

- Information System and Programming
- Algorithm and complexity

Syllabus

From a technical point of view, we will aim to develop by a team a complete infrastructure for collecting, processing and displaying data from sensors. Data from other project groups in other STs will pushed and hosted on a local server but will then be pushed onto a cloud-like infrastructure. At this stage, no treatment is performed. The data is then re-extracted and can be processed to be projected into a final data model suitable for presentation. This data will be stored in a database to be implemented by the development team. This data is then presented via a REST API to the part of the team developing the application frontend.

Class components (lecture, labs, etc.)

Students will be divided into a project team organized around a project leader (which can change every day). At the beginning of the day, each project team will be given features to be provided at the end of the day. In addition, every day, minor improvements will have to be made in order to respond as quickly as possible to the needs expressed by students from other STs during a meeting bringing together all the ST students concerned.

To support the EI, it is expected:

1. a computer room that can accommodate up to 25 people
2. access to a Cloud Computing infrastructure
3. possible VPNs to connect the different software components

Grading

Oral presentations

Resources

- computers
- sensors for testing and from other STs

Learning outcomes covered on the course

- Understand and model the client requests
- Implement as a team a solution answering the client requests

Description of the skills acquired at the end of the course

- C4.1 Analyse customer needs, the constraints of other stakeholders as well as include societal challenges.
  Evaluated by a presentation of the global solution fully integrated with the development of other ST.

- C7.1 Persuade at the level of core values; to be clear about objectives and expected results.
  Evaluated by a non technical presentation of the global solution in coordination with other ST.

SCIENCE AND ENGINEERING CHALLENGE N°7 COURSES

ST7 - 71 - STOCHASTIC FINANCE AND RISK MODELLING

Dominante : MDS (Mathematics, Data Science)

Langue d'enseignement : English

Campus : Paris-Saclay

Engineer problem

The financialization of the economy is a remarkable phenomenon in the past thirty years, which pushes financial markets to the heart of the globalized economy. Accordingly, risk management by financial institutions is crucial to the economy as a whole.

The subject aims to introduce the fundamental concepts of financial risk management to students, and in particular the corresponding mathematical aspects. This module will allow the students to be familiar with stochastic models of asset pricing in discrete time, to discover common derivative products and to address real issues of risk management. For engineers working in the financial industry, the understanding and full control of these models are essential.

Prerequisites

Students are required to have followed the courses CIP, PDE and Algorithms and complexity. The knowledge of measure theory (found in CIP) is essential, e.g. sigma-algebra, measurable space, measure/probability, conditional expectation, etc.

Nevertheless, the ST4 Data and Statistics in Finance is NOT necessary.

Modules and challenges : A series of conferences will present different fields of financial risk management methods and their applications. Themes and speakers may change every year. Conferences may deal with :

- derivatives products ;
- asset management: portfolio allocation and risk management ;
- actuarial science and risk management of insurance ;
- commodities and energy markets ;
- etc.

Specific course (60 HEE) : Modeling of financial risks

Quick description : This course is an introduction to discrete time financial mathematics. It deals in particular with the valuation and hedging of derivative products as well as risk management in a stochastic discrete time framework.

Content : Discrete time market models. Arbitrage. European derivatives. Complete/uncomplete market. Evaluation. Hedging. Risk measurs and portfolio optimization. American derivatives.

Tutor class (TD) : Various questions/problems arising in finance are formulated in mathematical language. Theorems/tools/techniques presented during the course are needed to solve them.

Due to the reform on the course, slight modification to the course may be adopted. More details can be found in Edunao.

Project : Financial risk management

Associate partners : Industrial partners may change every year. Recent partners include BNP Paribas, Generali, HSBC, etc.

Location : Paris-Saclay

Quick description : Students enrolled in this course are asked to study a quantitative method in a financial risk management setting. Subjects are proposed by an industrial or academic partner.

Goals: to be able to model problems of financial risk management, to be able to implement numerical solutions.

Each project deals with a quantitative method for risk management, e.g., pricing or hedging of a financial product, or asset allocation, portfolio management, client portfolio analysis, etc. Real financial or client data is provided by the project partner. Each project requires the coding of the method investigated.

Students will work in groups (group formation rules will be specified at the start of the ST).

Evaluation : Students will be graded respectively for the course and the project.

Course : The score of final exam. More details can be found during the first class or in Edunao.

Project : Final grade is decided after an oral presentation, by a jury including the industrial supervisor.

2SC7110 – Stochastic Finance and risk modelling

Instructors : **Gaoyue Guo**
Department : **DÉPARTEMENT MATHÉMATIQUES**
Language of instruction : **ENGLISH**
Type of course : **Specific course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

This course is an introduction to financial mathematics in discrete time, with a focus on derivatives pricing/hedging and risk measures in a discrete-time stochastic framework.

Quarter number

ST7

Prerequisites (in terms of CS courses)

1st year Mathematics and Computer Science courses (CIP, EDP, Algo et complexité, Statistiques)

Syllabus

Stochastic calculus in discrete time. Introduction to financial derivatives. Financial market modelling in discrete time. Towards continuous time and the Black-Scholes model. Risk measures. Porfolio optimization.

Class components (lecture, labs, etc.)

Lectures (18h), tutorials (9h) and labs (6h)

Grading

Homework (50%) and final exam (50%).

Course support, bibliography

Lecture notes of CIP;
Föllmer, H., & Schied, A. (2011). *Stochastic finance: an introduction in discrete time*. Walter de Gruyter.

Learning outcomes covered on the course

The subject aims to introduce the fundamental concepts of financial risk management to students, and in particular the corresponding mathematical aspects. This module will allow the students to be familiar with stochastic models of asset pricing, to discover common derivative products and to address real issues of risk management.

2SC7190 – Risk Management on financial markets

Instructors : **Gaoyue Guo**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **ENGLISH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

Students enrolled in this course are asked to study a quantitative method in a financial risk management setting. Subjects are proposed by an industrial or academic partner.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Stochastic Finance and Risk Modelling (ST7 MDS)

Syllabus

Each project deals with a quantitative method for risk management, e.g., pricing or hedging of a financial product, or asset allocation, portfolio management, client portfolio analysis, etc. Real financial or client data is provided by the project partner. Each project requires the coding of the method investigated.

List of 2021 subjects (may differ in 2022):
- Optimal portfolio allocation (in partnership with BNP Paribas)
- Optimization for insurance products (in partnership with Generali)
- Hybrid portfolio optimization (in partnership with Volga Technologies)
- Heuristic portfolio construction (in partnership ODDO BHF)

Class components (lecture, labs, etc.)

Project with regular supervision. Short lectures if needed.

Grading

Source code, technical report and oral presentation

ST7 - 72 - OPTIMIZATION OF NETWORK INFRASTRUCTURE FOR SMART CITIES

Dominante SCOC (Systèmes Communicants et Objets Connectés)

Langue d'enseignement : English

Campus : Paris-Saclay

Introduction

The advent of the Internet of Things and the proliferation of applications based on cheap sensor networks are now paving the way for the development of smart, connected and sustainable cities. Many cities in Europe (Antony, Dijon, Malaga, Santander, Barcelona, etc.) are in the process of creating intelligent environments with experiments deployed for better adaptive management of traffic and transport, for better management of energy and water consumption, for reduction of CO_2 and pollution level, and for a better quality of life, etc. The creation and management of smart cities require high-speed communications infrastructures and edge networks for the collection, delivery and processing of a large amount of information (traffic sensors, cameras, localizable vehicles, profiles and movements of users / people, etc.), which will overload current telecommunications networks and / or require the development of new communication systems. It is estimated that the density of connected objects in smart cities will reach one million objects per km2 in the next years. Obviously, the optimization of communications networks is essential in this case. In this context, one of the main objectives of the fifth generation of communications systems is to be able to meet the needs of smart cities, in particular by allowing the communication of a large number of machines, the virtualization of network functions, and the intelligent data processing. This ST will present the current challenges and problems of smart cities, through interventions by the main actors in the field. The fundamental principles of game theory (rationality, Equilibria, etc.) will then be explained in detail and several practical examples of the use of this theory to solve smart city problems will also be presented and analyzed.

Prerequisites

Basics in Modelling and signal processing.

Context and Challenges Modules:

These modules include seminars on smart cities (issues, challenges, and experiments), a Panel dedicated to markets and economic models confronting the visions of the main actors in the field, as well as presentations by industrial partners focusing on technological and scientific challenges.

Specific Course (60 HEE): Game Theory for smart cities

Brief description:
This course explains the fundamental principles of game theory (rationality, Nash equilibrium, correlated equilibria, etc.) and presents the solution of several types of games (finite games and mixed strategies, revolutionary games, repeated games, etc.). Several practical examples of the use of game theory in smart cities are presented and analyzed. In particular, the distributed optimization of telecommunications network infrastructures, the routing of data in networks and the problem of intelligent vehicle charging are studied.

Project : Smart cities : the connected cities

Partners : Orange, Nokia, Thales

Place: Paris-Saclay

Brief description:

The projects are centered around practical applications of optimization (combinatorial, convex) and game theory to the current problems of smart cities. The projects will be multidisciplinary and will serve to put into perspective the courses of ST7 and to introduce students to engineering problems and/or scientific research in the field.

Examples of projects: collect and routing of data in smart cities, route optimization for cycling, optimization strategies for charging bikes at station, electrical consumed energy forecasting, etc.

The practical context of the project is related to a precise service in smart cities (information gathering from sensors, temperature regulation, video surveillance, consumption of electric energy, route optimization for cycling, etc.) and it will be given as a complement to the courses. Students will propose and implement convex optimization or game theory algorithms seen in the courses. They will then test their approaches on potentially real data.

2SC7210 – Game Theory for Smart Cities

Instructors : **Mohamad Assaad**
Department : **DÉPARTEMENT SIGNAL, INFORMATION, COMMUNICATION**
Language of instruction : **ENGLISH**
Type of course : **CSpecific course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

This course explains the fundamental principles of game theory (rationality, Nash equilibrium, correlated equilibria, etc.) and presents the solution of several types of games (finite games and mixed strategies, revolutionary games, repeated games, etc.). Several practical examples of the use of game theory in smart cities are presented and analyzed. In particular, the distributed optimization of telecommunications network infrastructures, the routing of data in networks and the problem of smart vehicle charging are studied.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Communication networks (basic notions), optimization

Syllabus

- General introduction
  - smart cities and game theory
  - Game theory: normal and extensive form
  - Decision and solution concepts (rationality, Nash equilibrium, etc)
  - Correlated Equilibria
- Different Game types and application to the problems of smart cities

a. Zero sum and non zero sum games
b. Finite games and mixed strategies
c. Routing games
d. Revolutionary games
e. Repeated games
f. Stable Matching: stable mariage games

- Case Study: Application to smart charging problems, application to frequency allocation in wireless networks

Class components (lecture, labs, etc.)

Organization of the lectures

- General Introduction: 6h CM + 1.5 TD
- Different types of games (zero sum, routing, etc.): 9h CM + 7.5h TD
- Case study: 3h CM

Grading

- Final Exam - 1.5h

Course support, bibliography

- Rida Laraki, Jérôme Renault, Sylvain Sorin, Bases Mathématiques de la Théorie des Jeux, Ecole Polytechnique, 2013.
-E. Altman, Advances in Dynamic Games and Applications, 2013
- D.Bertsekas and J. Tsitsiklis, Parallel and Distributed : Numerical Methods, athena scientific, 2015.
- D. Bertsekas and R. Gallager, Data Networks, Prentice Hall.
- Chen, C., Zhu, S., Guan, X., Shen, X.S, Wireless Sensor Networks : Distributed Consensus Estimation, Springer, 2014.
- G. Ferrari, Sensor Networks : Where Theory Meets Practice, Springer-Verlag, 2009.
- Recent papers on IoT, smart cities and wireless networks.

Resources

Lecturers: Mohamad Assaad (CS), Mikael Touati (Orange Labs)

Exercices sessions (TD): 25 students per classroom
software to use: Matlab

Learning outcomes covered on the course

At the end of the course the student will be able to:

1- know various emerging problems in smart cities (telecommunications networks, smart charging, etc.)
2- model a network in the context of smart cities with its main functions
3- formulate emerging problems in smart cities using distributed optimization and tools from Game Theory
4-know the tools of game theory and their use in smart cities
5-implement game theory algorithms in Matlab

Description of the skills acquired at the end of the course

C1.1: "be able to make the list of parameters that impact the studied system, the list of elements with which it is in relation" and "know how to identify the important parameters with respect to the problem posed"

C1.2: "Know how to use a model presented in class in a relevant way. Make the choice of simplifying assumptions adapted to the studied problem"
C1.3: "Solve a problem using an approach based on approximation", "Make a relevant simulation choice for a given problem " and
"Know the limitations of numerical simulations and what one can expect from, know how to criticize results of numerical simulations"

2SC7290 – Smart cities: connected cities

Instructors : **Mohamad Assaad**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **ENGLISH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

The projects are centered around practical applications of optimization (combinatorial, convex) and game theory to the current problems of smart cities. The projects will be multidisciplinary and will serve to put into perspective the courses of ST7 and to introduce students to engineering problems and/or scientific research in the field.
Examples of projects: gathering and routing of data in smart cities, route optimization for cycling, optimisation strategies for charging bikes at station, electrical consumed energy forecasting, etc.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Communication networks (basics), optimization, Matlab

Syllabus

Examples of projects: gathering and routing of data in smart cities, route optimization for cycling, optimisation strategies for charging bikes at station, electrical consumed energy forecasting, etc.
The practical context of the project is related to a precise service in smart cities (information gathering from sensors, temperature regulation, video surveillance, consumption of electric energy, route optimization for cycling, etc.) and it will be given as a complement to the courses. Students will propose and implement convex optimization or game theory algorithms seen in the courses. They will then test their approaches on potentially in real data.

Class components (lecture, labs, etc.)

Each project is assigned on average to five students and is mainly supervised by a professor. Some projects are jointly proposed with some industrial partners and are hence co-supervised by engineers from these companies. A room dedicated to the projects will be available to students. The supervisors will follow up regularly (one meeting / group / week at the beginning and one daily meeting per group during the final week). Inter group collaboration will be encouraged (whenever it is possible), and students will be assessed on their ability to work in teams (leadership, tasks' sharing, communication).

Grading

report to write+defense (per group)

Resources

software to use: Matlab

Learning outcomes covered on the course

At the end of the project the student will be able to:

1- know emerging problems in smart cities (telecommunication networks, routing of data, smart charging, etc.)
2- model a network in the context of smart cities with its main functions
3- formulate emerging problems in smart cities as optimization frameworks
4-implement convex optimization and game theory methods in Matlab

Description of the skills acquired at the end of the course

C1 : Analyse, design and implement complex systems made up of scientific, technological, social and economic dimensions.
C1.1 : Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem
C1.2 : Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem
C1.3 : Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation
C1.4 : Design, detail and corroborate a whole or part of a complex system.
C1.5 : Bring together broad scientific and technical concepts in a core structure contained within the framework of an interdisciplinary approach.
C2 : Acquire and develop broad skills in a scientific or academic field and applied professional areas
C2.1: Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.
C2.3 : Rapidly identify and acquire the new knowledge and skills necessary in applicable / relevant domains, be they technical, economic or others.
C3 : Act, engage, innovate within a scientific and technological environment
C3.1 : Be proactive and involved, take initiatives
C3.2 : Question assumptions and givens. Overcome failure. Take decisions
C6 : Thrive in an international and multicultural environment
C6.1 : Identify and use the necessary software for one's work (including collaborative tools) and adapt digital responses according to the context.
C8 : Lead a team, manage a project
C8.1: Work collaboratively in a team.
C8.2 : Train and motivate a group, demonstrating effective leadership.
C8.4 : Work using project management techniques appropriately tailored to the situation.
C9 : Think and act as an accountable ethical professional
C9.2, : Identify, within a given structure, the scope of liability as well as socio-ethical and environmental responsibilities.
C9.4 : Demonstrate rigour and critical thinking in approaching problems from all angles, be they scientific, social or economic.

ST7 - 73 - CIRCULAR ECONOMY AND INDUSTRIAL SYSTEMS

Dominante**:** GSI (Large Interacting Systems), VSE (Living-Health-Environment), CVT (Construction, City and Transport)

Langue d'enseignement **:** French

Campus **:** Paris-Saclay

Engineering problem

Companies are becoming **actors in the transition to a more environmentally friendly economy**. For example, several of them called for a strong agreement at COP21 and since then more and more of them are deciding to act and transform their practices towards more "circular" models. This new way of doing business translates into action several mutually reinforcing factors: the **growing awareness of the challenges of the ecological and energy transition**, the **multiplication of initiatives on a territorial scale**, the **strengthening of laws and standards towards a more sustainable economy**, and market balances that are changing **and making sustainable practices more profitable**.

The **circular economy** aims to **move away from a culture of extraction and waste and to optimize the use of resources** to minimize the impact of human activities on the environment. **Industrial ecology** is a scientific approach to **integrated metabolism** that makes it possible to implement this circular economy, via - among other things - **industrial synergies** (pooling of material, water or energy flows between companies), the **eco-design** of products and services, or the economy of functionality.

It is a **formidable field of innovation**, **commercial differentiation** and a sustainable and **profitable growth relay** that is emerging. **This circular economy needs leaders capable of understanding the issues at stake, trained to initiate and manage ambitious projects at the level of companies and territories.**

This Engineering Challenge Term (*Séquence Thématique*) tackles in detail Circular Economy through **engineering strategies, methods and tools** that allow its implementation (thus this is not an economy course). It alternates between theory (course), application (tutorial classes, academic project, industrial project), and activities by industrial or institutional partners (conferences, workshops, industrial project).

Adviced prerequisites

None

Context and issue modules:

The introduction of the sequence is organized around three half-days aiming at presenting the sequence, the projects and introducing the issues of the Circular Economy, with the following activities:

- Introductory conferences and round table: introduction to Circular Economy by field actors (National Institute of Circular Economy, Law firm specialized in Circular Economy)
- Discovery workshops: workshop "Impacts of the Smartphone" (example of the Fairphone), workshop "Circular business models" (example of the SEB company), introductory workshop to Life Cycle Assessment (Waro, start-up created by alumni)
- Industrial conferences (each year different)

Specific course (60 HEE) :

Circular Economy and Industrial Ecology Methods

Brief description: The course aims to go through the different dimensions of the Circular Economy to give students an overview of the field. Then the focus will be on the operational tools of Industrial Ecology that students will learn

to manipulate (Material Flow Analysis, Life-Cycle Assessment and circularity indicators tools) to carry out an "academic" project by modeling material and energy flows and by measuring environmental impacts. These tools can be used in the industrial project of the thematic sequence.

Projects:

The sequence is built around an industrial project; 4 topics in connection with industrial partners will be proposed to students, including at least one project carried by the VSE major and one by the CVT major. The topics described below are those of past years and are provided for information purposes only. Those of 2024 will be on similar topics.

Project #1 (example 2020 to 2023) : **Biorefinery : optimization of flows and/or associated processes**

Industrial Partner : Chair of Biotechnology, ARD

Location : Paris-Saclay + visit of the biorefinery of Pomacle (CEBB and partner industrial site)

Short description :

The biorefinery can be defined as an industrial ecosystem that transforms biomass (agro resources and animal waste) into several products from alimentary to energy, chemicals, raw materials, cosmetics, health…). France is a leading country in this field at the international level, thanks to the biorefinery located in Pomacle Bazancourt, which treats more than 4 Mt of biomass per year. The biorefinery is, therefore, a relevant industrial tool to accompany the ecological transition, first to answer the issue of climate change and second to help the industrial relocation, especially in territories of agricultural and forestry production. The biorefinery also contributes actively to Sustainable Development (environment, economy, and social pillars). The project aims to map the different production units and characterize and quantify the inputs and outputs streams. Second, from this exploration phase, the goal is to propose new stream exchange architecture to optimize the environmental footprint of the biorefinery. The proposed approach is multidisciplinary and mixes data science, modeling-simulationoptimization, process engineering, and industrial engineering. The students are expected to work in a group to identify, develop and present operational solutions that reduce the environmental impact of the biorefinery.

Project #2 (example 2021) : **ESA_Lab@CentraleSupélec**

Industrial Partner : Agence Spatiale Européenne (ESA)

Location : Campus Paris-Saclay

Short description :

The MELiSSA project of ESA aims at developing a regenerative support life system to reproduce the main function of the Earth ecosystem (water and oxygen production), in a limited mass and volume and with an exterme security. MELiSSA is on of the most accomplished Circular Economy example in the world, considering loops of material and energy flows. ESA_Lab@CentraleSupélec, created in 2020, is a privileged collaboration framework between ESA and CentraleSupélec. Its objective is to develop the interest and knowledge of peaceful space exploration activities, and associated transverse applications, like climate observation, Earth observation, navigation, (cyber)security, artificial intelligence, sustainability, spatial economy..., to the mutual benefit of the two organizations and the Society. This ST7 projects aims at specifying and proposing first scenarios of the preliminary design of a future "demonstration lab", that will be a place of scientific experiments and projects around Circular Economy and with close links with MELiSSA. The project is structured in two main phases: (1) Specification of the demonstration lab: needs and first ideas identification, thanks to a literature review and interviews with CentraleSupélec stakeholders and ESA experts; (2) Preliminary design of the demonstration lab.

Project #3 (example 2022 and 2023) : **Laptop reconditioning**

Industrial Partner : Emmaüs Connect

Location : Campus Paris-Saclay + visit of a laptop reconditioning center

Short description :

Member of Mouvement Emmaüs, Emmaüs Connect is a French association created in 2013 to fight digital divide and digital illiteracy. Emmaüs Connect launched in November 2020 LaCollecte.tech, a platform that allows organizations to provide a second life to their unused digital devices to the benefit of people in social and digital insecurity. The project aims at fostering laptop reconditionning for the 8 million of French citizens who do not have access to the internet and thus to first need services (while in the meantime, 33% of companies own dormant devices they are not able to value). Four axes were studied (each group of students handled two of them): (1) imagine a "universal" shell that would allow to recreate a new second hand laptop with any resued component; (2) design a tool to assess the compatibility of laptop components from different brands, different models and based on available stocks; (3) study the feasibility of a laptop whose motherboard would be a Raspberry Pi (because laptop's motherboards are very hard to reuse as components are very often welded); (4) propose advocacy measures for laptop manufacturers to promote the evolution of their industrial practices towards more circularity and sustainability.

Project #4 (example 2022) : **Circolab student trophy**

Industrial Partner : association professionnelle Circolab

Location : Campus Paris-Saclay + visit of the building site of the olympic village (Saint-Denis

Short description :

Circolab is a professional association of organizations from the real estate and building sector aiming at promoting circular economy in their activities. Circolab launched in 2022 the very first edition of the Circular Economy Trophy intended for engineering and architecture students, including CentraleSupélec. Several case studies were proposed to students with a common objective: propose realistic and quantified circular economy initiatives at the scale of a building or a city district. The ST7 students worked on two case studies associated with the futur athletes' village for the Olympic Games in Paris in 2024: (1) A case proposed by SOLIDEO (organization in charge of the construction of olympic works) at the scale of a city block to imagine solutions for circularizing water flows; (2) A case proposed by Vinci at the scale of another city block to imagine solutions to maximize the valorization of equipments (partition walls, furniture, bathrooms) between the phase "Games" (= during the games) and the phase "Legacy" (= after the games, when the village will become a housing, offices and shops district).

Recent industrial partners : BNP Paribas, Cap Gemini, SIA Partners

Academic CS partner : Quantitative Finance Team, MICS Lab

2SC7310 – Circular economy and industrial ecology methods

Instructors : **Yann LEROY, François CLUZEL**
Department : **DÉPARTEMENT GÉNIE INDUSTRIEL ET OPÉRATIONS**
Language of instruction : **FRENCH**
Type of course : **Specific course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

According to ADEME (French environmental protection agency), Circular Economy aims at shifting the current paradigm based on linear economy, by limiting the waste of resources and environmental impacts, and by increasing the efficiency at all stages of products economy. It is composed of 7 pillars: sustainable procurement, eco-design, industrial and territorial ecology, functional economy, responsible consumption, longer duration of use, recycling and waste recovery.

Industrial Ecology is an approach whose objective is to limit the impacts of industry on the environment. It aims at considering an industrial system as a whole to identify, model and optimize material and energy flows, as well as associated environmental impacts. It aims at reproducing a natural system in the human activities, where all material and energy flows are reused, where the notion of waste does not exist anymore. All economic sectors are concerned.

The course's objective is to cover the different dimensions of circular economy to provide to the students a global vision of the field. Then the focus will be made on the operational engineering tools of industrial ecology, which students will learn to manipulate (Material Flow Analysis (MFA, tool to map material and energy flows), LCA (Life-Cycle Assessment, tool to calculate environmental impacts) and circularity indicators) to drive industrial ecology projects. All of part of these tools will be directly used for the project of the engineering challenge term.

Quarter number

ST7

Prerequisites (in terms of CS courses)

None

Syllabus

The course is structured into one 1.5-hours session and ten 3-hours sessions.

1. Introduction to Circular Economy and environmental impacts (Yann Leroy and/or François Cluzel)

A. The Pillars of Circular Economy
The sessions 2-6 are built on the following format: lecture and workshop on an industrial case study. These sessions go through the 7 pillars of Circular Economy according to the ADEME's definition.
2. Product End-of-life (Yann Leroy and/or François Cluzel)
3. Ecodesign, extension of product lifespan and responsible consumption (Yann Leroy and/or François Cluzel)
4. Sustainable procurement (Yann Leroy and/or François Cluzel)
5. Functional economy and responsible consumption (ATEMIS)
6. Industrial and Territorial Ecology (Yann Leroy and/or François Cluzel and/or Andreas Hein)

B. Methods and tools for Industrial Ecology

The sessions 7-10 (Yann Leroy and/or François Cluzel) are dedicated to Material Flow Analysis (MFA), Life Cycle Assessment (LCA) and Circularity and Sustainability Indicators (lectures and workshops). These three approaches will be applied on a case study in group.

12. Final exam : duration 1h30

Class components (lecture, labs, etc.)

According to specific needs, the sessions will alternate lectures and tutorials on industrial case (case study and or serious games), and tutorials on MFA and LCA professional software (used during the project of the Engineering Challenge Term). Some sessions may be organized as flipped classrooms.

Grading

Final written exam (1.5-hours on Evalmee: quiz + essay, 50%) + evaluation of tutorials (per group) for sessions 7-10 (50%)

Course support, bibliography

- Adoue, C., 2007. Mettre en œuvre l'écologie industrielle. PPUR, Lausanne.
- Buclet, N., Barles, S., 2011. Écologie industrielle et territoriale : Stratégies locales pour un développement durable. Presses Universitaires du Septentrion, Villeneuve d'Ascq, France.
- Erkman, S., 2004. Vers une écologie industrielle, 2e éd. ed. Charles Léopold Mayer, Paris.
- Hawken, P., Lovins, A., Lovins, L.H., 1998. Natural Capitalism: Creating the Next Industrial Revolution, 1st edition. ed. US Green Building Council, Boston.

Resources

Teachers: François Cluzel, Yann Leroy (researchers at the Industrial Engineering Research Department) and some other researchers, PhD students or external speakers
Software: Life-Cycle Assessment (OpenLCA or Waro) and Material Flow Analysis (Stan)

Learning outcomes covered on the course

1. Be aware of major environmental stakes
2. Know the 7 pillars of circular economy
3. Master the main engineering tools of industrial ecology: Material Flow Analysis, Life-Cycle Assessment, Circularity and Sustainability Indicators
4. Be able to model and simulate an industrial system in a circular economy perspective
5. Be able to optimize an industrial system in a circular economy perspective

Description of the skills acquired at the end of the course

C2 Développer une compétence approfondie dans un domaine d'ingénieur et dans une famille de métiers

- C2.1 Approfondir un domaine des sciences de l'ingénieur ou une discipline scientifique à Jalon 2 : Approfondir l'ensemble de ses connaissances sur un domaine choisi, via les enseignements de 2A
- C2.3 Identifier et acquérir de façon autonome les nouvelles connaissances et compétences nécessaires àJalon 2 : Assimiler les nouvelles connaissances au sein d'outils ou méthodes opérationnels et efficients pour le problème donné

C9 Penser et agir en ingénieur éthique, responsable et intègre en prenant en compte les dimensions environnementales, sociales et sociétales

- C9.1 Analyser et anticiper les conséquences possibles de ses choix et de ses actes dans le respect de soi-même, d'autrui et de l'environnement à Jalon 2 : Identifier la responsabilité en termes individuels, la sienne et celle des autres, et en termes collectifs à court et à long termes. Situer son action et ses conséquences potentielles

2SC7390 – Circular Economy industrial project

Instructors : **François CLUZEL**
Department : **DOMINANTE - CONSTRUCTION VILLE TRANSPORTS, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION, DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT**
Language of instruction : **FRENCH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

The Circular Economy industrial project is a core element of ST7 Circular Economy & Industrial Systems. Every year, 4 subjects in close relation to industrial partners are proposed to students, including at least one project leaded by the Major VSE (Vivant, Santé, Environnement), and one by the Major CVT (Construction, Ville, Transports). During the first project session, at the beginning of ST7, subjects are presented to students that provide then their preferences (MyWay campaign). Student are assigned to one project by maximizing their satisfaction and respecting the quotas (all subjects have to be filled). Each projet is coached by one or two teachers, and by one or several industrial partners. This project is not a school project; a mission is given to the students, answering to real needs, and they work with real data provided by the industrial partners (and most often students sign a Non-Disclosure Agreement). Their first mission is to understand and reformulate the problem asked. Thus, subjects and partners evolve each year to fit with the "current needs", even if some continuity exist with some partners/subjects (for example the subjects Biorefinery or Sustainable Building). The proposed subjects are all dealing with Circular Economy, but with different points of view and objectives (optimization of flow or processes, territorial approach implying a fine consultation of stakeholders, technico-economic study, prospective study, business models definition, ...) that allow each student to deepend a particular dimension of Circular Economy in accordance with his/her preferences.

Quarter number

ST7

Prerequisites (in terms of CS courses)

None

Syllabus

The project will be spread over 6 to 8. Students will have to divide the tasks and roles within their groups, and they will use agile project management. Around the middle of the project, one session will be dedicated to an intermediary oral presentation. Finally, the final oral defense will happen during the very last session. Students will deliver after this defense a finalized version of their group report. Subjects described below are from the two past years, and provided for information only. Subjects for the 2023 edition will deal with similar or close areas.

Project #1 (example 2020 to 2023) : Biorefinery : optimization of flows and/or associated processes
- Industrial Partner : Chair of Biotechnology, ARD
- Location : Paris-Saclay + visit of the biorefinery of Pomacle (CEBB and partner industrial site)
- Short description : The biorefinery can be defined as an industrial ecosystem that transforms biomass (agro resources and animal waste) into several products from alimentary to energy, chemicals, raw materials, cosmetics, health…). France is a leading country in this field at the international level, thanks to the biorefinery located in Pomacle Bazancourt, which treats more than 4 Mt of biomass per year. The biorefinery is, therefore, a relevant industrial tool to accompany the ecological transition, first to answer the issue of climate change and second to help the industrial relocation, especially in territories of agricultural and forestry production. The biorefinery also contributes actively to Sustainable Development (environment, economy, and social pillars). The project aims to map the different production units and characterize and quantify the inputs and outputs streams.

Second, from this exploration phase, the goal is to propose new stream exchange architecture to optimize the environmental footprint of the biorefinery. The proposed approach is multidisciplinary and mixes data science, modeling-simulationoptimization, process engineering, and industrial engineering. The students are expected to work in a group to identify, develop and present operational solutions that reduce the environmental impact of the biorefinery.

Project #2 (example 2021) : ESA_Lab@CentraleSupélec
- Industrial Partner : Agence Spatiale Européenne (ESA)
- Location : Campus Paris-Saclay
- Short description : the MELiSSA project of ESA aims at developing a regenerative support life system to reproduce the main function of the Earth ecosystem (water and oxygen production), in a limited mass and volume and with an exterme security. MELiSSA is on of the most accomplished Circular Economy example in the world, considering loops of material and energy flows. ESA_Lab@CentraleSupélec, created in 2020, is a privileged collaboration framework between ESA and CentraleSupélec. Its objective is to develop the interest and knowledge of peaceful space exploration activities, and associated transverse applications, like climate observation, Earth observation, navigation, (cyber)security, artificial intelligence, sustainability, spatial economy..., to the mutual benefit of the two organizations and the Society. This ST7 projects aims at specifying and proposing first scenarios of the preliminary design of a future "demonstration lab", that will be a place of scientific experiments and projects around Circular Economy and with close links with MELiSSA. The project is structured in two main phases: (1) Specification of the demonstration lab: needs and first ideas identification, thanks to a literature review and interviews with CentraleSupélec stakeholders and ESA experts; (2) Preliminary design of the demonstration lab.

Project #3 (example 2022 and 2023) : Laptop reconditioning
- Industrial Partner : Emmaüs Connect
- Location : Campus Paris-Saclay + + visit of a laptop reconditioning center
- Short description : Member of Mouvement Emmaüs, Emmaüs Connect is a French association created in 2013 to fight digital divide and digital illiteracy. Emmaüs Connect launched in November 2020 LaCollecte.tech, a platform that allows organizations to provide a second life to their unused digital devices to the benefit of people in social and digital insecurity. The project aims at fostering laptop reconditionning for the 8 million of French citizens who do not have access to the internet and thus to first need services (while in the meantime, 33% of companies own dormant devices they are not able to value). Four axes were studied (each group of students handled two of them): (1) imagine a "universal" shell that would allow to recreate a new second hand laptop with any resued component; (2) design a tool to assess the compatibility of laptop components from different brands, different models and based on available stocks; (3) study the feasibility of a laptop whose motherboard would be a Raspberry Pi (because laptop's motherboards are very hard to reuse as components are very often welded); (4) propose advocacy measures for laptop manufacturers to promote the evolution of their industrial practices towards more circularity and sustainability.

Project #4 (example 2022) : Circolab student trophy
- Industrial Partner : association professionnelle Circolab
- Location : Campus Paris-Saclay + visit of the building site of the olympic village (Saint-Denis
- Short description : Circolab is a professional association of organizations from the real estate and building sector aiming at promoting circular economy in their activities. Circolab launched in 2022 the very first edition of the Circular Economy Trophy intended for engineering and architecture students, including CentraleSupélec. Several case studies were proposed to students with a common objective: propose realistic and quantified circular economy initiatives at the scale of a building or a city district. The ST7 students worked on two case studies associated with the futur athletes' village for the Olympic Games in Paris in 2024: (1) A case proposed by SOLIDEO (organization in charge of the construction of olympic works) at the scale of a city block to imagine solutions for circularizing water flows; (2) A case proposed by Vinci at the scale of another city block to imagine solutions to maximize the valorization of equipments (partition walls, furniture, bathrooms) between the phase "Games" (= during the games) and the phase "Legacy" (= after the games, when the village will become a housing, offices and shops district).

Class components (lecture, labs, etc.)

Project-based learning
Agile project management
Group work with support from supervisors
Several scheduled exchanges with the industrial partners
Use of Teams to facilitate exchanges and group work

Grading

Students are evaluated on the quality of their oral presentation and deliverables, including a writen debriefing (individual and group grade).
Their grade will be based in particular on a handout specifying the specific tasks and roles of each student in each group.
Oral presentation: 35%.
Report and deliverables: 65%.

Course support, bibliography

Slideshows and ST7 specific course materials
Slides of the different presentations
Previous years' reports and deliverables
Documents and data provided by the industrial partners.

Resources

Teaching staff : François CLUZEL (LGI), Yann LEROY (LGI), Franck MARLE (LGI), Julien LEMAIRE (LGPM – Chair of biotechnology), one supervisor from the Major CVT
Software tools : to be defined according to the needs (for exemple LCA software (OpenLCA or Waro) and MFA software (Stan))
According to the subjects, travels will be organized (industrial visit, interviews of stakeholders...).

Learning outcomes covered on the course

1) Be aware of major environmental issues
2) Mastering the main tools of industrial ecology: MFA and LCA
3) Know how to model and simulate an industrial system in a circular economy perspective
4) Knowing how to optimize an industrial system in a circular economy perspective
5) Knowing how to organize in interdependent teams and manage a project
6) To know how to define a study perimeter and precise objectives to meet industrial needs.
7) Knowing how to reduce the complexity of a problem in a relevant way
8) Dealing with uncertainty or lack of data
9) Take a critical look at data and models

Description of the skills acquired at the end of the course

C2 Développer une compétence approfondie dans un domaine d'ingénieur et dans une famille de métiers

- C2.4 Produire des données et développer de la connaissance selon une démarche scientifique à Jalon 2 : Exploiter un ensemble cohérent de données et réaliser un état de l'art exhaustif avec un esprit critique
- *Pour certains :* C2.5 Développer les savoir-faire et savoir-être d'un des métiers de l'ingénieur à Jalon 2 : Interagir avec une posture appropriée au contact d'un milieu professionnel (entreprise, laboratoire ou autre organisation)

C4 Avoir le sens de la création de valeur pour son entreprise et ses clients

- C4.1 Identifier et (re)formuler le besoin de création de valeur du client ainsi que les enjeux et contraintes associés. Identifier et intégrer les autres parties prenantes, internes et externes ainsi que les autres dimensions non évoquées initialement (techniques, économiques, humaines, etc.) à Jalon 2 : Identifier avec le client les autres parties prenantes (internes et externes) et leurs liens ainsi que, si possible, les autres dimensions ne figurant pas dans la formulation initiale : techniques, économiques, humaines, etc. Ceci afin d'avoir une formulation plus complète et plus riche de la question posée.
- C4.2 Proposer une ou des solutions répondant à la question reformulée en termes de création de valeur et compléter par l'impact sur les autres parties prenantes et par la prise en compte des autres dimensions. Quantifier la valeur créée par ces solutions. Arbitrer entre des solutions possibles à Jalon 2 : Elargir à l'impact sur les autres parties prenantes et dans le périmètre fixé dans le jalon 2 de C4.1

C6 Être opérationnel, responsable et innovant dans le monde numérique
C7 Savoir convaincre

- C7.1 Sur le fond : Structurer ses idées et son argumentation, être synthétique (hypothèses, objectifs, résultats attendus, démarche et valeur créée) à Jalon 2 : Adapter le fond et son argumentation en fonction d'interlocuteurs ou de contextes élargis, « avoir du répondant » pour défendre sa solution (maîtrise du sujet des interlocuteurs, valeurs, engagements, disponibilité, attention, etc.).
- C7.4 Sur les techniques de communication : Maitriser le langage parlé, écrit et corporel, et maitriser les techniques de base de communication à Jalon 2 : Déployer avec succès des techniques de communication adaptées à la situation spécifique, parmi lesquelles : rhétorique, storytelling, langage corporel, occupation d'espace, respiration, mémoire, supports visuels, outils vidéos, distanciel, etc.

C8 Mener un projet, une équipe

- *Pour certains :* C8.2 Mobiliser et entrainer un collectif en faisant preuve de leadership à Jalon 2 : Mobiliser l'équipe jusqu'au résultat final dans un projet « par temps calme autant qu'en tempête » (projet subissant des contraintes exogènes, gestion des aléas, des parties prenantes, etc.)
- *Pour certains :* C8.4 Travailler en mode projet en mettant en œuvre les méthodes de gestion de projet adaptées à la situation à Jalon 2 : Maitriser et utiliser pertinemment une méthode avancée de développement projet (Management agile de projet complexe, chaine critique, holacratie, …) et les outils associés et les mettre en œuvre tout au long d'un projet simple en faisant les ajustements nécessaires.

ST7 - 74 - OPTIMIZATION OF PASSENGER TRANSPORT SYSTEMS

Dominante **:** Info&Num (Computer Science & Digital), GSI (Large Interacting Systems)

Langue d'enseignement **:** French

Campus **:** Paris-Saclay

Engineering problem

Transportation systems are essential to today's society because they provide crucial mobility services for both personal and business travel. The massification of travel and the diversity of mobility services, as well as new autonomous vehicles, make these systems complex to size, design and operate.

The optimization of such systems is therefore essential. For an airline, it is particularly important to be able to :

- take advantage of available information to forecast demand on "origin-destination" routes and define flight schedules that best cover the demand,

- Pricing flights to ensure the best possible fill rate and revenue management for the company,

- to size the services (check-in, baggage, ...) at the hubs allowing to operate the flight plans,

- planning flight crew schedules in accordance with legislation and crew preferences,

- assigning aircraft to flights in order to minimize costs, and being robust to possible delays.

Beyond the ability to operate efficiently, the engineer's role is also to inform strategic decisions through quantitative models evaluating different scenarios in which a company might choose to engage.

Adviced prerequisites SIP and Algorithms and Complexity Course

Context and issue modules:

These modules include an introductory lecture on the topic, presentations on the technological and scientific challenges of passenger transport optimization, and a presentation of related projects.

Specific course (60 HEE) : Decision support / Operational research (AD/OR)

Brief description :

Optimization and decision making is an intrinsic activity of the engineer/manager profession. In order to understand the complex decision problems they will be confronted with, tomorrow's engineers and managers must have the concepts and methods of optimization to formalize a decision problem. The course aims at introducing a certain number of classical models allowing to represent and solve decision problems in different contexts. The aim is to present models of different concrete decision problems.

Project:

The project aims at putting the students in a real situation of solving a decision problem involving the formulation of a model, the choice of a resolution method(s), the implementation of a solution allowing a resolution on real data sets, the validation of the solution by numerical tests. The objective of the project through this activity is to make the students progress in the comprehension of the scientific, technical, but also human and economic stakes which underlie the implementation of a project of operational research and decision support in an organization.

Project n°1: Optimization of rail transport operations

Associate partner: SNCF

Location: Paris-Saclay

Brief description:

In rail transport, the implementation of passenger service involves dealing with various operational management problems: forecasting passenger demand, designing timetables, pricing seats, assigning trains to platforms in a station… These examples involve optimizing the operation of the transport system. The project will deal with one of these rail operations management issues.

Project n°2: Optimization of an airline's operations

Associate partner: Air France - Operational Research / Artificial Intelligence Group

Location: Paris-Saclay campus

Brief description:

This project deals with one of the multiple problems of managing the operations of an airline company: for example, assigning flights to boarding gates, placing passengers in a plane, assigning planned flights to a fleet of planes, etc.

Project n°3 : Planning of a mobile team

Associated partner: Decision Brain

Location: Paris-Saclay campus

Brief description :

The aim of this project is to design and implement a planning tool for a mobile team of technicians, initially planned to create the daily routes of 500 technicians who have to carry out some 10 000 tasks.

2SC7410 – Decision Support : Models, algorithms and implementation

Instructors : **Vincent Mousseau**
Department : **DÉPARTEMENT GÉNIE INDUSTRIEL ET OPÉRATIONS**
Language of instruction : **FRENCH**
Type of course : **Specific course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

Decision making is an intrinsic activity in the engineering profession and often leads to optimize one or more aspects of a system. But these decisions are also based on the judgments/preferences of a decision-maker/user. Preferences have therefore played a key role in many computer applications and modern information technologies. This is the case of computer marketing, recommendation systems, adaptive user interfaces, ... Decisions can be strategic, tactical or dynamic, in complex, competitive, uncertain, optimize or find a compromise between conflicting criteria ... To solve the complex decision problems between them, they must be confronted, the engineers must implement the concepts and methods and algorithms to formalize a problem of decision.

Quarter number

ST7

Prerequisites (in terms of CS courses)

none

Syllabus

- Introduction to decision making, basic concepts,
- Modeling of decision problems using mathematical programming. Presentation of modeling and resolution tools (modelers and solvers),
- Implementation using Python + GUROBI,
- Decision in the presence of risk, decision in the uncertain, utility theory, decision trees,

- Multi-criteria decision and modeling of preferences, aggregation models,
- Empirical analysis of decision behavior,
- Learning preference models from data, incremental learning,
- Metaheuristics for combinatorial problems,
- Multiobjective optimization,

Class components (lecture, labs, etc.)

lectures: 13.5h
exercices: 10,5h
lab: 9h
this distribution may slightly vary

Grading

Final exam (1h30): 70% Lab evaluation: 30%

Course support, bibliography

Lecture slides and exercices will be provided.
Labs will beorganized using a Jupyter notebook

bibliography:
D. Bouyssou, T. Marchant, M. Pirlot, P. Perny, A. Tsoukiàs, P. Vincke “Evaluation and Decision models: A critical perspective”, Kluwer, 2000.
W. Cooper, L. Seiford, and K. Tone, “Introduction to Data Envelopment Analysis and its use”, Springer, 2006.
C. Guéret, C. Prins, M. Sevaux. "Programmation linéaire, 65 problèmes d’optimisation modélisés et résolus avec Visual Xpress", Eyroles, 2003
C. Kwon, "Julia programming for operations research", 2019, second edition, http://www.chkwon.net/julia
P. Vallin, D. Vanderpooten, “Aide à la décision, une approche par les cas”, 2e édition, Ellipses. 2002.
H.P. Williams. "Model building in mathematical programming". J. Wiley, New York, 2013. 5ème édition,

Resources

equipe enseignante (V. Mousseau + chargés de TD/TP à valider)
Software: Python + optimisation solvers + metaheuristics libraries
TD: ~30 students
TP: ~20 students
Wifi ABSOLUTELY REQUIRED for TD and TD

Learning outcomes covered on the course

This course aims to develop students' abilities to develop and implement models and algorithms relevant to a decision-making situation.
At the end of the course, students will master some methods / models for decision support. They will be able to manipulate models, use them in an operational way and implement them efficiently. They will also have the necessary elements to take a step back and have a critical sense in relation to these methods, and thus to distinguish their performances and their limits of application.

Description of the skills acquired at the end of the course

C1 (all sub-competences): Analysis, design and implementation of complex systems made up of scientific, technological, social and economic dimensions.
C2.1: Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.
C2.3: Rapidly identify and acquire the new knowledge and skills necessary in applicable / relevant domains, be they technical, economic or others.
C6.3: Conceive, design, implement and authenticate complex software.
C6.4: Solve problems through mastery of computational thinking skills.
C6.5: Operate all types of data, structured or unstructured, including big data.

2SC7490 – Passenger transport systems optimization

Instructors : **Vincent Mousseau**
Department : **DOMINANTE - GRANDS SYSTÈMES EN INTERACTION, DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRENCH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Quarter number

ST 7

ST7 - 75 - SIMULATING INDUSTRIAL FLOWS

Dominante: : GSI (Large Interacting Systems) and VSE (Living-Health, Environment)

Langue d'enseignement : French

Campus : Paris-Saclay

Engineering problem

The growing complexity of products and services, the globalization of operations and the increasing demands of customers place the issue of flow management at the heart of the concerns of industrial and service companies.

The competitiveness of these companies is strongly linked to their ability to organize themselves to produce and distribute products and services that meet customer expectations while ensuring the sustainability of the company in its economic, social and environmental dimensions.

One of the major challenges to meet these objectives is to optimize the management of flows, from suppliers to end customers.

This topic addresses these issues, and focuses particularly on one approach to understanding and managing industrial flow approaches: discrete-event simulation.

Adviced prerequisites None

Context and issue modules: These modules will include presentations by industrial partners to illustrate the problems of flow management in different sectors.

Specific course (60 HEE) : Optimization and management of flows

Brief description : Product flow in a factory, parcel flow in a post office, patient flow in a hospital, customer flow in a supermarket: the problems related to the understanding and management of flows are present in all sectors of activity. More than a specific problem, flow management is an approach to industrial problems that can be adapted to many sectors. Knowing how to understand and control flows is a major challenge for industrial performance. This course introduces the problems related to industrial flow management and presents a tool to tackle these problems, discrete event simulation.

Project: Flow management in industrial gas delivery

Associated partner: Air Liquide

Location: Paris-Saclay

Short description : This project will allow, on an industrial case proposed by a partner, the application of the tools seen in the specific course, and in particular of the discrete event simulation of industrial flow systems. It will consist in defining a conceptual model, transposing it into a computer model, validating this model, experimenting with it, and building a recommendation for managers based on the simulation results.

2SC7510 – Managing and optimising industrial flows

Instructors : **Guillaume LAMÉ, Adam ABDIN**
Department : **DÉPARTEMENT GÉNIE INDUSTRIEL ET OPÉRATIONS**
Language of instruction : **FRENCH**
Type of course : **Specific course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

Production flows in factories, patient flows in hospitals, customer flows in supermarkets: understanding and managing flows is an issue in all industrial activities. Beyond specific issues, flow management is an overarching approach that can be adapted in many industrial situations.

Understanding and controlling flows is a major component of industrial performance. This module provides an introduction to industrial flow management. The use of discrete event simulation to tackle these issues is presented.

Quarter number

ST7

Prerequisites (in terms of CS courses)

none

Syllabus

Principles of discrete-event simulation of systems of industrial flows.
Use of Simul8 for discrete-event simulation.
Optimisation of flow systems.
Use of OptQuest coupled to Simul8 for simulaiton-optimisation.
Perspectives on the industriel implementation of these techniques.
Industrial case studies.

Class components (lecture, labs, etc.)

The module will comprise lectures, either presential or as videos and reading assignments to prepare individually, and study cases and exercises.

Grading

90 minutes written exam (40%) and intermediate assignment (60%).
The intermediate assignment is a compulsory assessment

Course support, bibliography

Exercises and study cases, lecture notes, videos.

Textbook for this course: Robinson S. Simulation the practice of model development and use. 2nd ed. London: Palgrave Macmillan 2014.

Resources

Discrete-event simulation software Simul8, and the extension OptQuest for simulation-optimisation.

Simul8 only exists for Windows. Students using Mac OS will need to install a virtual machine, which may slow down the simulation softare and compromise its general usability.

Lectures, videos, exercises and industrial study-cases.

Learning outcomes covered on the course

After this module, students will be able to use simulation and optimisation approaches to understand and improve the performance of a flow system.

This course will address the following competencies:

- C1 Analysing, designing and realising complex systems with scientific, technological, human and economic components
  - C1.2 Using and developpping relevant models, choosing the righjt modelling scale and simplifying hypotheses to address the problem
  - C1.3 Resolving the problem through approximating, simulating and experimenting
- C2 Developing specific knowledge of a scientific or industrial domain et a professional domain
  - C2.1 Exploring a scientific or engineering domain or discipline
- C3 Acting, innovating in a scientific and technological environment
  - C3.6 Evaluating the effectiveness, feasibility and robustness of proposed solutions

Description of the skills acquired at the end of the course

Use of discrete-event simulation fo rmodelling industrial systems, and implementation on Simul8.

2SC7591 – Flow management in industrial gas delivery

Instructors : **Guillaume LAMÉ, Loïc Pineau**
Department : **DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **FRENCH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

Students will apply the tools provided in the associated course on an industrial case study proposed by a partner. In particular, they will be able to implement discrete event simulation on a long and in-depth case study.

Quarter number

ST7

Prerequisites (in terms of CS courses)

none

Syllabus

In parallel with the associated ST7 course, students will progressively apply the techniques taught in the course on a real complex industrial problem.
Course reminders will be provided as needed.

Class components (lecture, labs, etc.)

Industrial case study.

Grading

Group project, with a written report and a final defence.

Course support, bibliography

Contents from the ST7 course.
Data from the industrial case study.

Resources

Industrial case study, with data and information on the context and the industrial challenge, supervised by a tutor.
Discrete-event simulation software Simul8, and the extension OptQuest for simulation-optimisation.

Simul8 only exists for Windows. Students using Mac OS will need to install a virtual machine, which may slow down the simulation software and compromise its general usability.

Learning outcomes covered on the course

Implementation of discrete event simulation. Conceptual modelling, implementation into a computer simulation model, model validation, experimentation.
This course will address the following competencies:

- C1 Analysing, designing and realising complex systems with scientific, technological, human and economic components
  - C1.2 Using and developping relevant models, choosing the righjt modelling scale and simplifying hypotheses to address the problem
  - C1.3 Resolving the problem through approximating, simulating and experimenting
- C2 Developing specific knowledge of a scientific or industrial domain et a professional domain
  - C2.1 Exploring a scientific or engineering domain or discipline
- C3 Acting, innovating in a scientific and technological environment
  - C3.6 Evaluating the effectiveness, feasibility and robustness of proposed solutions
- C7 Being convincing.
  - C7.1 Being clear on objectives and expected results. Being rigorous on the hypotheses and the method. Structuring ideas and arguments. Highlighting value creation.
- C8 Leading a project, a team.
  a. C8.1 Working as a team/collaboratively.
  b. C8.4 Working in project mode, using project management techniques as required by the situation.

Description of the skills acquired at the end of the course

Implementation of discrete event simulation on a real case-study.

ST7 - 76 - HIGH PERFORMANCE SIMULATION FOR FOOTPRINT REDUCTION

Dominante: MDS & INFO-NUM

Langue d'enseignement : English

Campus : Paris-Saclay

General description of the thematic sequence

Simulation is nowadays at the heart of many design and optimization approaches to reduce the footprint or the impact of the products created: reduction of the risk of destruction in case of natural disasters, reduction of an airplane's drag to minimize the fuel consumed and the CO2 emitted, reduction of the time of a large-scale calculation and of the resources used (the simulations themselves end up consuming a lot of energy on a lot of processors),...

But these are often complex system simulations, which require both skills in high performance and large scale simulations, and in optimization methods to limit the scope of investigations and the hours of computation required. Moreover, each study must still be done by seeking a compromise between the quality of the solution found and the number of hours of computation used, because hours of computation are expensive (especially on high-performance computation clusters or on a large scale in clouds). It is therefore essential to learn how to manage a quota of computing hours.

This ST thus includes numerical mathematics, parallel computing, optimization methods, and development and experimentation on PC clusters or in clouds. Students will learn:

- to develop parallel modeling and simulations to reduce the duration of the most expensive phase of the optimization loop,

- to associate these simulations with adapted optimization methods and algorithms, which will minimize the number of configurations to be simulated and evaluated (brute force approaches will be avoided)

- to experiment the programming of high performance computing platforms (PC clusters or clouds),

- to exploit these platforms under the constraint of a quota of hours of calculations not to be exceeded.

Organization of the thematic sequence

- Context and issues modules

The modules presenting the context and the issues will begin with a presentation of the objectives and organization of the ST. Then, a succession of presentations by industrial partners will illustrate different cases of use of high performance simulation for footprint reduction (reduction of energy consumption, reduction of financial cost, reduction of simulation time, reduction of data volumes...). On this occasion, the associated scientific and technical challenges will be identified, as well as the induced needs in optimization.

The topics of the ST projects will also be presented during the context and stakes modules: in aeronautics, in seismic exploration, in infrasound wave detection, in risk calculation on the cloud, and in temporal and energy optimization of parallel calculations. These presentations will also present the economic and societal issues related to the investments required to carry out high-performance simulations, and the impact of simulation on the evolution of the technologies that surround us.

A visit of the Very Large Computing Center (TGCC) in Bruyères-le-Châtel, under the leadership of the CEA, will allow to see modern infrastructures of high performance computing, and their support infrastructures (power supply, cooling, protections). Finally, a round table with all the industrial partners will allow to discuss the trends for the future.

- Specific course "Parallel computing and optimization

This course includes mathematical, numerical, algorithmic and programming aspects on parallel and distributed machines, associated with optimization issues.

Among the notions covered, this course describes, in a first part, the basics of parallel and distributed computing, by detailing in particular the computer architectures and parallel programming models as well as the parallel and distributed algorithms used on these architectures. In a second part, this course presents parallel optimization methods and algorithms, commonly used in parallel computing codes. Two classes of methods used for optimization problems are successively discussed, namely parallel partitioning and domain decomposition methods, and genetic algorithms and parallel meta-heuristics. These methods and algorithms will be used in the different integration courses of this ST, in order to deal with problems from the engineering sciences. In a third part, this course focuses on the performance analysis of the developed solutions. The notions of performance metrics and scaling, as well as the analysis of experimental performances are also studied.

Industrial partners and proposed project topics

- **The CEA DAM (Direction des Applications Militaires) proposes a study of "Optimization of a seismic exploration campaign for the protection of structures**

(Optimization of a seismic exploration)

CEA-DAM is the French warning center for tsunamis and strong earthquakes, and uses its high-performance computing resources for various missions.

After the Fukushima accident (Japan), the use of high performance computing resources has become more and more common for the estimation of the seismic risk associated with nuclear power plants: within the framework of the design of new plants, but also in order to study the performance of existing plants in the face of extreme events, not foreseen at the time of their design.

This study concerns the optimization of a geophysical exploration campaign on an experimental site, using its digital twin. The project consists in optimizing (minimizing) the number of sensors needed to discover the geological configuration of the site of interest. Many realistic simulations using the SEM3D code (Reverse Time Migration method) will have to be called in an optimization loop. We will therefore look for an optimization method that allows us to achieve a good quality of optimization while respecting the time quota.

The calculations will be done on machines of the Moulon mesocenter, under the constraint of a quota of calculation hours.

- **ONERA (Office National d'Etudes et Recherche Aérospatial) proposes a study of "Optimization of shapes and reduction of drag in aeronautics".**

(Drag reduction in aeronautics)

Recent studies show that air traffic is constantly increasing. Without improvements in aircraft performance in terms of energy consumption, the share of air transport in greenhouse gas emissions may become unbearable in the future. Reducing aircraft fuel consumption requires both an increase in engine efficiency and an improvement in aircraft aerodynamics and weight reduction.

Numerical tools have been widely used for a long time in the aeronautical field to help in the design and optimization of systems. For example, the shape of a wing can be improved in order to reduce its drag, at constant lift, or its internal structure can be lightened. The optimization methods require successive calculations for different wing geometries. The higher the accuracy of the numerical models, the higher the computational costs for each step. The only way to reduce the computation time to be able to integrate the optimization methods in the industrial design cycle is to use parallel computers. The objective of this project is to realize the parallelization of the most expensive part of the optimization phase, i.e. the resolution of large linear systems from finite element models on large meshes, and to experiment with different sets of optimization parameters.

The tests will be carried out on the parallel machines of the CentraleSupélec Teaching Data Center, under the constraint of a quota of computing hours.

- **The CEA DAM (Direction des Applications Militaires) proposes a study of "Optimization of infrasound detection for the verification of the Comprehensive Nuclear Test Ban Treaty".**

(Detection of infrasound waves)

CEA-DAM is the French warning center for tsunamis and strong earthquakes, and also participates in the implementation of the verification means of the Comprehensive Nuclear Test Ban Treaty (CTBT) by using its high performance computing resources.

A parallel compressible hydrodynamics code has been developed at CEA DAM, which allows the simulation of blast wave and acoustic wave propagation in the presence of terrain and buildings, with or without wind. On the other hand, it is considered that judiciously placed sensors allow the recording of overpressure signals in case of an explosion. Two types of problems can then be studied: (1) find the location of an explosion and determine its power from the recordings of sensors located in the field, (2) define where to judiciously position sensors to maximize the chances of detecting an explosion within a given area.

A "brute force" investigation simulating all possible configurations of the parameters would consume too many hours of computation. We will therefore develop an optimization loop exploring the space of possible configurations sparingly and using the hydrodynamics code efficiently.

The computations will be done on CEA clusters under constraints of a quota of computation hours, and three of the last days of the study will take place on the Bruyères-le-Châtel site. This study is reserved for students from the European Union.

- **ANEO is an IT company expert in high performance computing and cloud operation, which proposes a study of "Energy optimization and acceleration of a financial computation graph on cloud".**

(Graph of financial calculations)

One of the difficulties in assessing the accounts of an insurance company (or a bank) lies in the valuation of financial assets (shares, life or car insurance contracts, etc.) and the underlying risks. Depending on the valuation of the risks taken, the regulations resulting from the various economic crises oblige the insurance company or the bank to immobilize a certain amount of equity capital.

The steps of such a calculation, managed by ANEO, form a task graph with numerous dependencies, and the sum of the execution times corresponds to the equivalent of 413177 hours of calculation. On an infrastructure of 1700 cores the computation time would be a little more than 10 full days if all cores could work at any time. But because of the dependencies between the computational tasks, it happens that there are not enough tasks to occupy all the allocated resources, and the process finally takes more than 10 days.

In order to optimize the cost of this computation, we want to: (1) use on-demand resources available in the cloud, and (2) optimize the execution of the task graph by looking for the best turn-on/off strategy for the compute nodes, and the best scheduling of tasks on the available nodes. To do this, we will develop a cost function that calculates the execution time of the task graph as a function of a node management and task scheduling strategy, and we will implement an optimization algorithm that seeks the best parameterization of this strategy.

- **INTEL proposes a study of "Low Cost Optimization of Acoustic Wave Propagation Code Performance".**

(Reducing the footprint of a code)

Any high performance application running on a parallel machine has many configuration parameters in its source code and compilation, which have a significant impact on its performance and energy footprint. But the behavior of the application depends on the architecture of the processors used, the test case data and the software configuration of the machine. In the end, this behavior is extremely difficult to model, and the configuration parameter space can be very large. The use of optimization algorithms therefore appears fundamental to converge towards a configuration of the application minimizing its execution time and its energy footprint on the machine used.

However, each execution of a test case of an HPC application can be long, even on a parallel machine. We will therefore target optimization methods that are not too greedy in terms of the number of experiments, so that the pre-stage of optimizing the HPC code does not itself consume too many computing resources! This amounts to looking for a compromise between the energy spent to optimize an HPC code, and the energy saved by this application once optimized.

The tests will be carried out on the parallel machines of CentraleSupélec's Teaching Data Center, under the constraint of a quota of computing hours.

2SC7610 – Parallel Computing Methods and Algorithms, and Optimization Methods

Instructors : **Frédéric Magoules**
Department : **DÉPARTEMENT INFORMATIQUE**
Language of instruction : **ENGLISH**
Type of course : **Specific course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

Simulation is today at the heart of many design and optimization approaches, to reduce the impact of the products created: reducing the carbon footprint, the sound footprint ... Such problems are often complex systems, whose simulation requires specific skills in high performance and large scale simulations.

In this course, students will learn to develop models and simulations without limit on the size of the problem, without sacrificing the accuracy of computations. For this purpose:

- They will design models based on blocks of operations which can be run in parallel.
- They will design distributed algorithms that can be deployed on a growing number of processors as the size of the problem increases, without sacrificing accuracy of results.
- They will identify mathematical optimization methods adapted to the problem.
- They will experiment parallel programming for optimization.

Quarter number

ST7

Prerequisites (in terms of CS courses)

1. SG1 common course « Systèmes d'Information et Programmation » (1CC1000)
2. ST2 common course « Algorithmique et complexité » (1CC2000)
3. Basic knowledge in linear algebra

Syllabus

Architecture and low level programming
- Parallel and Distributed Architectures
- Compilation, Serial Optimisations sérielles, Auto-Vectorisation
- Jobs and tasks scheduling
- Homeworks: Examples of code vectorisation (with office hours)

Parallel and distributed programming
- Multithreading on Multicores - Message Passing : point-to-point communications, collective communications, deployment on multicore clusters
- Homeworks: Examples of 1D and 2D algorithms, performance modeling (with office hours)

Parallel and distributed algorithms
- Introduction to gradient algorithms
- Methodology of parallelization for the gradient algorithm

- Implementation on parallel computers

- Homeworks: analysis of a modification of an algorithm based on different steps (with office hours)

Domain decomposition methods for optimisation
- Introduction to minimization algorithms in the context of optimization
- Parallel Domain decomposition methods
- Graph partitioning techniques
- Methodology of parallelization
- Minimization of communications

Combinatorial optimisation
- Combinatorial Optimisation - local methods
- Combinatorial Optimisation - population based methods

Performance and scalability metrics and analysis

- Performance Metrics, Scalability

Application to mechanics
- 2D analysis of a dam
Homework: implementation and analysis of a mechanical problem (with office hours)

Class components (lecture, labs, etc.)

Lectures (21,0 hours) and tutorials (4,5 hours) and office hours (4,5 hours) with written final exam (1,5 hours) and continuous evaluation.

Grading

Evaluation 100% with a written final exam split between : AA.1 and AA.3 evaluated at 85% by the first part of the exam, and AA.2 and AA.3 evaluated by the second part of the exam and 15% by the homeworks.

Course support, bibliography

- Frédéric Magoulès, François-Xavier Roux, Guillaume Houzeaux. Parallel Scientific Computing. Wiley & Sons, Inc., 2015. Hardcover 354 pages (in English). This course support is also available in other languages: in French (Dunod, 2017), in Spanish (CIMNE, 2014), in Japanese (Morikita Publishing Co Ltd, 2015), in Hungarian (Pollack Press, 2018).
- Frédéric Magoulès, Stéphane Vialle. Parallel and Distributed Computing, Numerical Methods: Slides of the lectures

Resources

- Teachers : Filippo GATTI et Frédéric MAGOULES et Stéphane VIALLE
- Lectures and tutorials composed on group of 25 students working on computers.
- Access to various clusters (Data Center for Education of CentraleSupelec, and Mésocentre de CentraleSupelec-ENS Paris Saclay).
- Validation with standards languages: C/C++/Python, message passing interface library (MPI).

Learning outcomes covered on the course

AA.1 At the end of the lectures, students will be able to parallelize computation kernels, through domain decomposition methods, involved in optimization techniques (core skills C2.1 and C3.6).

AA.2 At the end of the lectures, students will be able to parallelize optimization methods based on genetic algorithms, and heuristics methods (core skills C1.3 and C3.6).

AA.3 At the end of the lectures, students will be able to implement parallelization techniques allowing to solve a problem in a limited time and where the sequential solution is not possible in a limited time (core skills C3.6).

Description of the skills acquired at the end of the course

C1.3 Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation

C2.1 Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.

C3.6 Evaluate the efficiency, feasibility and strength of the solutions offered. / proposed solutions

2SC7691 – Optimization of a seismic exploration campaign for infrastructure protection

Instructors : **Stephane Vialle, Filippo GATTI**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES, DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **ENGLISH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

Project of the ST7 "High Performance Simulation for Footprint Reduction",
Project topic in partnership with CEA-DAM.
Majors: Computer Science (INFONUM) & Math, Data Sciences (MDS).

After the accident in Fukushima (Japan), the use of high-performance computing has become increasingly common in estimating the seismic risk associated with nuclear power plants. These tools are of strategic importance not only in the context of the design of new installations, but also in order to study the performance of existing power plants in the face of extreme vents, not anticipated during their design. In this context, the SEISM Institute (of which CentraleSupélec and CEA are founders) was founded in 2012. It is a French scientific grouping, comprising academic and industrial partners (including CEA and EDF), with the 'objective of bringing together the various know-how in seismology and earthquake engineering to improve the prediction of the seismic response of critical sites and structures in France, as well as the assessment of the associated risk.
In this context, this project concerns the optimization of a geophysical exploration campaign on an experimental site, using its digital twin, built using a wave propagation code (SEM3D) in development between CentraleSupélec, CEA and the Institute of Globe Physics. SEM3D simulates the propagation of seismic waves over large 3D domains, with domain decomposition on a Cartesian (or spherical) mesh. It also integrates the site topography and complex geological structures. The project therefore consists of solving an inverse problem in order to optimize - using SEM3D - the geological configuration of the site of interest. This optimization is based on the *Reverse Time Migration* method (i.e. resolution by adjoint problem). The optimization strategy provides for many realistic simulations, from source to sensors (forward) and back-propagation of the misfit (backward) in order to be able to update iteratively the mechanical properties of the subsoil. Indeed, given the size of the site of interest (~10 km wide) and the spatial resolution sought (~100m), although SEM3D is parallelized and distributed on supercomputers, each wave propagation simulation can last several hours on many shared computing cores. For this, at each iteration, the *Forward* and *Backward* steps must be properly chained with an appropriate job scheduling strategy (launch of batch calculations). Finally, the number of sensors for in situ recordings must be reduced, given the associated costs, in terms of sensors, acquisition campaigns and storage of the data obtained.

The objective of this study is therefore threefold:

1. propose a geology model minimizing the difference between simulation and records,

2. minimize the number of sensors required to arrive at a model at a reasonable financial cost (considering their spatial layout),

3. manage to design this solution over the duration of the project with high-performance computers and with a limited quota of computing hours.

For this purpose, an optimization loop will be developed using the wave propagation simulation code as efficiently as possible: by sparingly exploring the space of possible configurations, to economically find a good solution.

Technical details of the system:

The studied system consists of a sedimentary basin surrounded by outcropping bedrock, possible candidate for the construction of a new nuclear power plant. To evaluate the seismic response of the site and to propose possible earthquake scenarios, one needs to know:

- the 3D geometry of the geological layers,
- the mechanical properties of these layers.

This information is fundamental for the definition of site effects on seismic energy radiated by an active fault.

Quarter number

ST7

Prerequisites (in terms of CS courses)

First year courses:

1. SG1 common course "Systèmes d'Information et Programmation" (1CC1000)
2. ST2 common course "Algorithmique et complexité" (1CC2000)

Courses of the ST:

- ST7 common course "Optimisation" (2CC3000)
- ST7 specific course "Méthodes et algorithmes parallèles pour l'optimisation" (2SC7610)

Others prerequisites:

- Parts of common course "CIP - Convergence, Intégration et Probabilités" (1SL1000)
- Parts of common course "EDP - Equations aux dérivées partielles" (1SL1500)
- Knowledge of linear algebra will also be needed

Syllabus

Main tasks of the study:

- Presentation of the subject at the beginning of the first part of the project (intervention of CEA-DAM):
    - presentation of theoretical fundamentals in wave propagation in complex configurations,
    - presentation of scientific issues related to design earthquake-resistant nuclear power plants, to the evaluation of the seismic response of the site and the estimation of the associated risk.
- Formalization of the problem (and of its characteristic sizes) represented by the geophysical investigation to characterize the seismic response of a nuclear site. Choice of an optimization method adapted to problem. Development of the algorithm on a verification case, supported by the analytical solution.
- Identification of SEM3D code parameters and their respective impacts on its parallel execution time, handling of computing resources of the Moulon Mesocentre.
- Conception and implementation in Python of an optimization code calling SEM3D. The optimization code will itself be parallelized if its algorithm allows it (we would then have a parallel master code calling on request a parallel code).
- Test and debugging of the complete parallel optimization code on the Moulon Mésocentre supercomputers, on small and medium problems (low frequency and / or small size of the domain).
- Application to a real case (in terms of the size of the area studied, and maximum frequency):
    - test larger problems on a larger number of nodes and CPU cores (approach of scaling),
    - analysis of the quality of the solution found and of the performance of calculations,
    - code optimization to improve the solution found AND, if required, the performance of calculations,
- Estimate the minimum number of sensors needed to find a workable solution based on available resources and maximum duration of the study.
- The study will conclude with the submission of a report and a presentation to be evaluated: the quality of the solution found, the effectiveness and the possible extensions of the crafted optimization code, and the management of the computational resources and quota during the project.

Rmk : Different student groups will experiment different optimization methods, but they will test all several examples of *Reverse Time Migration* (terrestrial and marine geophysical prospecting).

Class components (lecture, labs, etc.)

Part 1 (40HEE):

- Steps 1 and 2: course complements, handling of computing resources, formalization of the problem, choice of an optimisation algorithm.
- Step 3 and 4: Python numerical implementation of the optimisation algorithm used for the Reverse Time Migration method. Result analysis of the geophysical propecting campaigns, in order to choose the parameters to optimize and to identify the sources of uncertainty and experimental noise.
- Step 5: first implementation of the optimisation algorithm on parallel machine, evaluation of the result quality and computation performances on small and medium size problems, and comparison to a reference analytical solution.

- Midterm report (slides and progress summary) and talk about current results and future work (part 2).

Part 2 - *final sprint* (40HEE):

- Step 6: experiments on real problems with different configurations, identification of the sources of performance locks and losses, and (if required) code improvement to push the limits of supportable problem size.
- Step 7: estimate of the number of sensors/records required for a stable optimisation, function of the available computing resources and of the maximum duration of the project.

- Final report (slides and extended abstract) and global talk about the project approach and results.

Grading

This project will be evaluated by a midterm talk at the end of part 1 (40HEE), and by a final talk at the end of part 2 (*final sprint* 40HEE). Talks will be done by the entire team, but will lead to individual marks in case of strongly heterogeneous teams.Each talk evaluation will consider the overall quality of the talk, of the slides and of the progress summary. Each talk mark will be 50% of the total mark.

Resources

Teaching staff:

1. **F. Gatti** (CentraleSupélec & MSSMat)
2. **M. Bertin** (CEA-DAM)

Workplace and computing resources:

- Students will work at CentraleSupelec, in a classroom with electrical outlets and reliable wifi Internet access (except lockdown).
- Students will use their laptops to connect to remote **PC clusters** at **Moulon Mesocenter.**
- Final oral exam will take place at CentraleSupelec the last afternoon of the project.

Learning outcomes covered on the course

When finishing the course, the students will be able to:

- **Learning Outcome 1 (AA1):** identify and parametrize an optimisation method adapted when each evaluation/iteration requires many computing resources and computation time,
- **Learning Outcome 2 (AA2):** implement and debug a sequential or parallel Python code on supercomputer (developped from scratch or using libraries), calling distributed C/C++ computing kernels,
- **Learning Outcome 3 (AA3):** deploy intensive computing applications on remote resources,
- **Learning Outcome 4 (AA4):** identify the limitations of the study, function of the available computing resources,
- **Learning Outcome 5 (AA5):** manage a computing resource quota, during an intensive computing campaign.

Description of the skills acquired at the end of the course

- C4: Have a sense of value creation for his company and his customers
- C7: Know how to convince
- C8: Lead a project, a team

2SC7692 – Shape optimization and drag reduction in aeronautics

Instructors : **Stephane Vialle**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES, DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **ENGLISH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

Project of ST7 "High Performance Simulation for Footprint Reduction".
Project topic in partnership with ONERA.
Majors: Computer Science (IN) & Math, Data Sciences (MDS).

Air traffic is steadily increasing each year to the point that, without improvements in aircraft performance in terms of energy consumption, the share of air transport in greenhouse gas emissions may become unsustainable in the future.

Aircraft consumption can be decreased by either increasing the engine efficiency or by improving the aerodynamic design of the aircraft, e.g. reducing the aircraft weight. Computational tools have been widely used in aeronautics for a long time to help design and optimize systems. For example the shape of a wing can be improved to reduce its drag, lift, or its inner structure can be lightened.

Technical details of the system and methodology:

Optimization methods require successive calculations for different wing geometries including the calculation of *adjoint models*. The computational costs for each step can become prohibitively expensive for high fidelity numerical models.

The only way to reduce computing times such that results can be obtained fast enough to integrate optimization methods into the industrial design cycle is to use parallel computers. In the case of optimization methods like efficient descent methods (such as the gradient method or the Newton method), the different configurations are not known a priori but determined successively by the algorithm. It is therefore necessary to parallelize each calculation of the *primal problem* and then the *adjoint problem*.

The objective of this project is to achieve the parallelization of the most expensive phase of the optimization loop, namely the resolution of large linear systems resulting from finite element discretization models on large meshes to experiment with different sets of optimization parameters.

For this, the parallelization will be performed, in a message exchange programming environment adapted to the use of very large computers with network computing nodes, by a domain decomposition approach. The global iterative resolution method will be accelerated by solving the local equations in each subdomain. The developed parallel code will be executed and evaluated on parallel machines of CentraleSupélec.

Quarter number

ST7

Prerequisites (in terms of CS courses)

First year courses:

- SG1 common course "Systèmes d'Information et Programmation" (1CC1000)
- ST2 common course "Algorithmique et complexité" (1CC2000)

Courses of the ST:

1. ST7 common course "Optimisation" (2CC3000)
2. ST7 specific course "Méthodes et algorithmes parallèles pour l'optimisation" (2SC7610)

Others prerequisites:

- Parts of common course "CIP - Convergence, Intégration et Probabilités" (1SL1000)
- Parts of common course "EDP - Equations aux dérivées partielles" (1SL1500)
- Knowledge of linear algebra will also be needed

Syllabus

Main stages of the study:

- Additional information on the subject at the beginning of the first part of the project (presented by ONERA):
  - presentation of fundamental theoretical tools in optimization used in aeronautics
  - presentation of the scientific issues related to the design of aircraft wings, the evaluation of the drag and the estimation of the associated risk when reducing the weight of the materials used.
- Formalization of the problem of representing geometry and structure to characterize the drag of an airplane wing. Use of a fixed optimization method adapted to the problem (method of geometry optimization using the Hadamard representation of the shape derivative). Development of the algorithm on a verification case supported by the analytical solution.
- Identification of the FENICS (OpenSource) code parameters for solving partial differential equations, and their impact on the quality of the flow calculation solution and on the execution time.
- Design and implementation in Python of an optimization code calling FEniCS; optimization code which will then be parallelized by message exchanges based on a domain decomposition approach.
- Test and development of the complete optimization code on a parallel machine of the CentraleSupélec Teaching Data Center, on small and medium problems (short duration of physical simulation, small size of the domain).
- Application to a real case (in terms of the size of the studied area, and geometry):
  - Experiments with larger problems on a larger number of nodes and computing cores (scaling approach),
  - Analysis of the quality of the solution and the performance of the calculations,
  - Optimization of the code to improve the solution quality AND, if needed, the performance of the calculations,
- Estimation of the optimal shape of the wing or flaps to reduce the drag of the flow.
- The study will conclude with the submission of a report and an oral presentation to evaluate: the quality of the proposed solution, the efficiency and extensibility of the algorithm in finding an optimal solution, and the management of the computation resource quota during the project.

Rmk: Different student groups will enforce different optimization methods, evaluated on different examples.

Class components (lecture, labs, etc.)

Part 1 (40HEE):

- Steps 1 and 2: course complements, handling of computing resources, formalization of the problem, introduction to the optimisation method.
- Step 3 and 4: Python numerical implementation of the optimisation algorithm used. Result analysis in order to choose the parameters to optimize and the quality of the solution.
- Step 5: first implementation of the optimisation algorithm on parallel machine, evaluation of the result quality and computation performances on small and medium size problems, and comparison to a reference analytical solution.

- Midterm report (slides and progress summary), and talk about current results and future work (part 2).

Part 2 - *final sprint* (40HEE):

- Step 6: experiments on real problems with different configurations, identification of the sources of performance locks and losses, and (if required) code improvement to push the limits of supportable problem size.
- Step 7: estimate of the optimal shape of the wing or shutters in order to reduce the airplane drag, function of the available computing resources and of the maximum duration of the project.

- Final report (slides and extended abstract) and global talk about the project approach and results.

Grading

This project will be evaluated by a midterm talk at the end of part 1 (40HEE), and by a final talk at the end of part 2 (*final sprint* 40HEE). Talks will be done by the entire team, but will lead to individual marks in case of strongly heterogeneous teams.Each talk evaluation will consider the overall quality of the talk, of the slides and of the progress summary. Each talk mark will be 50% of the total mark.

Resources

Teaching staff:

- **F. Magoules** (CentraleSupélec & MICS), and **S. Vialle** (CentraleSupélec & LISN)
- **S. Claus** and **F.-X. Roux** (ONERA)

Workplace and computing resources:

1. Students will work at CentraleSupelec, in a classroom with electrical outlets and reliable wifi Internet access.
2. Students will use their laptops to connect to remote PC clusters at the Data Center for Education of CentraleSupelec.
3. Final oral exam will take place at CentraleSupelec the last afternoon of the project.

Learning outcomes covered on the course

When finishing the course, the students will be able to:

- Learning Outcome 1 (**AA1**): identify and parametrize an optimisation method adapted when each evaluation/iteration requires many computing resources and computation time,
- Learning Outcome 2 (**AA2**): implement and debug a sequential or parallel Python code on supercomputer (developped from scratch or using libraries), calling distributed C/C++ computing kernels,
- Learning Outcome 3 (**AA3**): deploy intensive computing applications on remote resources,
- Learning Outcome 4 (**AA4**): identify the limitations of the study, function of the available computing resources,
- Learning Outcome 5 (**AA5**): manage a computing resource quota, during an intensive computing campaign.

Description of the skills acquired at the end of the course

- C4: Have a sense of value creation for his company and his customers
- C7: Know how to convince
- C8: Lead a project, a team

2SC7693 – Optimization of infrasonic wave detection for verification of the Comprehensive Nuclear-Test-Ban Treaty

Instructors : **Stephane Vialle**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES, DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **ENGLISH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

Project of the ST7 "High Performance Simulation for Footprint Reduction",
Project topic in partnership with CEA DAM.
Majors: Computer Science (INFONUM) & Math, Data Sciences (MDS).

Rmk : Project proposed to students of **European Union**

CEA-DAM uses high performance computing resources for its various missions, particularly in the environmental monitoring field (e.g. seismic or acoustic wave propagation phenomena). The “Département d'Ile de France” located in Bruyères-le-Châtel is thus the tsunamis and strong earthquakes french warning center. As part of its missions and based on its skills in the nuclear area as well as in detection and identification technologies, CEA-DAM also brings its expertise for fighting against nuclear proliferation and terrorism. In order to inform national authorities in case of a nuclear test, CEA-DAM thus participates in the implementation of verification means to assess the non-violation of the “Comprehensive Nuclear-Test-Ban Treaty” (CTBT).

The study proposed here concerns the characterization and detection of infrasonic waves at long distances, taking into account the topography and atmospheric conditions (e.g. wind here). A compressible 2D axisymmetric / 3D hydrocode which supports adaptive mesh refinement (AMR) and hybrid parallelism (MPI domain decomposition / OpenMP multithreading) on Cartesian grids is developed in our laboratory. It can simulate the propagation of blast and acoustic waves in the presence of relief and buildings, with or without wind. Judiciously located sensors allow overpressure signals recordings.

Two types of problems which will be solved with this AMR hydrocode are addressed here. The first one consists in localizing an explosion and determining its power on the basis of probes’ recordings located in the scene. The second one consists in defining judicious sensors locations in order to maximize the chances of detection in case of explosions in a given area. In both cases, a "brute force" investigation consisting in simulating all possible configurations before retaining the best one is unthinkable. It would consume gigantic hours of computations, which would make the design of the solution very long and overpriced.

For these two types of problems, the objective of this study is therefore twofold:

- Propose a solution to characterize the source of acoustic waves.
- Find this solution in a reasonable time on high-performance computers AND with a limited quota of computation hours.

To that end we will develop an optimization loop that uses the hydrocode the most efficiently as possible, by parsimoniously exploring the possible configurations space, to economically find a “good” solution.

Technical details of the studied systems

1. **1st topic: characterization of a source at the urban scale, taking into account buildings**

It consists in locating and determining the power of an explosion, following an accident or a malicious act, knowing only neighboring sensors recordings (whose locations are known). Buildings in the surrounding area will be taken into account. Here, the recordings will come out in practice from a simulation whose fictitious initial conditions (location and power of the source) will not be known by the students.

- **2nd topic: setting up a surveillance network**

  Here, it is question of designing a sensors network allowing the detection of hypothetic explosive experiments around an area that is under surveillance. These sensors - in limited numbers - should be judiciously located in order to maximize chances of detection whatever the weather (we will only consider wind here) and the relief are. Furthermore and for maintenance reasons, the sensors will only be located in so-called "accessible areas”.

Quarter number

ST7

Prerequisites (in terms of CS courses)

First year courses:

- SG1 common course "Systèmes d'Information et Programmation" (1CC1000)
- ST2 common course "Algorithmique et complexité" (1CC2000)

Courses of the ST:

- ST7 common course "Optimisation" (2CC3000)
- ST7 specific course "Méthodes et algorithmes parallèles pour l’optimisation" (2SC7610)

Others prerequisites:

- Parts of common course "CIP - Convergence, Intégration et Probabilités" (1SL1000)
- Parts of common course "EDP - Equations aux dérivées partielles" (1SL1500)
- Knowledge of linear algebra will also be needed

Syllabus

Main tasks of the study:

- More information at the beginning of the first part of the project (intervention of the CEA-DAM).
  - Presentation of physical principles and numerical methods used in the provided compressible hydrocode that will be used to simulate the propagation of blast and acoustic waves.
  - Identification of compressible hydrodynamic code parameters and their impact on the parallel execution time.
  - Handling resources in a remote computing center (at the CEA).
- Formalization of the problem and selection of values that are to be optimized. Choice of an optimization method adapted to the problem.
- Design and implementation in Python of an optimization code calling the parallel simulation code. The optimization code will itself be parallelized if allowed by its algorithm (we would then have a parallel master code calling on demand the parallel hydrocode).
- Tests and debugging of the complete optimization code on CEA’s parallel computers, on small and medium problems: simplified reliefs or buildings on reduced maps, without weather for 2D axisymmetric configurations (much faster).
- Scale up in terms of covered land size, and addition of relief and / or buildings and wind maps.
  - Experiments on bigger problems on a more large number of nodes and computing cores.
  - Analysis of the solution quality and the performances.
  - Code optimization to improve the solution found AND the computations performances.
- Estimation of the maximum size of the problem that can be handled regarding available resources and the study duration. Analysis of the feasibility of the extension to 3D cases over the time allocated for the project.
- Submission of a report and a presentation to evaluate: the quality of the solution found, the effectiveness and the extensibility of the code in finding an optimal solution, and the computation resource quota management that will have occurred during the project.

Rmk: the different groups of students will work on different topics (topics 1 and 2) and will implement different optimization methods.

Class components (lecture, labs, etc.)

Part 1 (40HEE):

- Steps 1 and 2: course complements, handling of computing resources, formalization of the problem, choice of an optimisation algorithm.
- Step 3: Python numerical implementation of the optimisation algorithm calling the compressible hydrodynamic parallel code, supplied by CEA DAM.
- Step 4: first executions on parallel machines of 2D simulations with basic configurations, debug of the algorithm and of the optimization code, evaluation of the result quality and computation performances on small and medium size problems, and comparison to a reference solution.

- Midterm report (slides and progress summary) and talk about current results and future work (part 2).

Part 2 - *final sprint* (40HEE):

1. Step 5: experiments on more complex and/or larger problems, similar to real problems, analyse of the quality of the computed solution, identification of the sources of performance locks and losses, and (if required) code improvement to push the limits of supportable problem size.
2. Step 6: estimate of the maximal problem size that can be processed, function of the available computing resources and of the maximum duration of the project, analyse of the feasibility of a 3D simulation.

- Final report (slides and extended abstract) and global talk about the project approach and results.

Grading

This project will be evaluated by a midterm talk at the end of part 1 (40HEE), and by a final talk at the end of part 2 (*final sprint* 40HEE). Talks will be done by the entire team, but will lead to individual marks in case of strongly heterogeneous teams.Each talk evaluation will consider the overall quality of the talk, of the slides and of the progress summary. Each talk mark will be 50% of the total mark.

Resources

Teaching staff:

- **J. Cagnol** (CentraleSupélec & MICS) and **S. Vialle** (CentraleSupélec & LISN)
- **T. Chantrait** (CEA DAM)

Workplace and computing resources:

- During the first part of the project:
  - Students will work at CentraleSupelec, in a classroom with electrical outlets and reliable wifi Internet access.
  - Students will use their laptops to connect to **remote powerful computing resources managed by CEA DAM**.
- During the second part of the project (*final sprint*):
  - Students will work **3 days on TGCC/TERATEC site, at Bruyères-le-Châtel.** CEA DAM will ensure the daily movement of students.
  - Final oral exam will take place at CentraleSupelec the last afternoon of the project.

Learning outcomes covered on the course

When finishing the course, the students will be able to:

- Learning Outcome 1 (**AA1**): identify and parametrize an optimisation method adapted when each evaluation/iteration requires many computing resources and computation time,
- Learning Outcome 2 (**AA2**): implement and debug a sequential or parallel Python code on supercomputer (developped from scratch or using libraries), calling distributed C/C++ computing kernels,
- Learning Outcome 3 (**AA3**): deploy intensive computing applications on remote resources,

- Learning Outcome 4 (**AA4**): identify the limitations of the study, function of the available computing resources,
- Learning Outcome 5 (**AA5**): manage a computing resource quota, during an intensive computing campaign.

Description of the skills acquired at the end of the course

- C4: Have a sense of value creation for his company and his customers
- C7: Know how to convince
- C8: Lead a project, a team

2SC7694 – Energy optimization and acceleration of a cloud financial calculation graph

Instructors : **Stephane Vialle**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES, DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **ENGLISH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,60**

Description

Project of the ST7 "High Performance Simulation for Footprint Reduction",
Project topic in partnership with ANEO.
Majors: Computer Science (INFONUM) & Math, Data Sciences (MDS).

Application Context

Modern **insurers** have a highly regulated but at the same time relatively broad field of activity: different types of insurance, banking services, etc. One of the difficulties in assessing the accounts of an insurance company (or bank) lies in the valuation of financial assets (e.g. EDF shares, life or car insurance contracts, etc.) and the underlying risks. The approach generally used consists of evaluating for each asset the cost of a devaluation as well as the associated risk. For simple assets such as shares, the calculation is simple. For more complex assets such as insurance products or derivatives, the calculation is more complex since it is usually based on the consideration of many factors. Depending on the valuation of the risks taken, regulations resulting from various economic crises, such as Solvency II or IFRS17, require the insurance or bank to tie up a certain amount of equity capital. Certain risks may cancel each other out between different assets (e.g. the risk of a life insurance asset based on the euro/dollar rate may be covered by other assets based on the euro/yen and yen/dollar rates). In order to maximise this potential for offsetting through the assets owned, these bodies will consolidate the accounts on the widest possible scale, the group as a whole. That is, they will carry out risk analyses as if all assets belonged to a single entity. One of the difficulties of the exercise then consists in distributing the capital requirement among the different legal entities whose accounts have been consolidated, so this process is actually more complex than a simple pooling of assets followed by a global risk analysis.

The ***process of constructing consolidated accounts for an insurance company therefore generates numerous calculations***. These calculations concern, on the one hand, the modelling of the cost of repayment of contracts according to various factors and, on the other hand, the modelling of investments made with the money available. As an example for a life insurance contract, risk modelling is based on mortality tables provided by INSEE and taking into account different factors such as geography, socio-professional category, family situation, etc. To do this, the life of the contract is simulated year after year in order to take into account changes in these factors. Different scenarios are played out in order to reflect all possible changes in situations (moves, changes in family situation, etc.). These scenarios are then aggregated. This process is of course a simplified view and does not take into account various elements such as the aggregation of contracts in order to reduce the volume of calculations, which aggregation is in itself the subject of various optimization works. Other elements of the process include the consolidation of asset/liability risks by contract type, consolidation by legal entity and taking into account the specific regulatory requirements of each country, and the use of these simulations to optimise the risk of the contracts offered as well as their price.

Problem addressed in this project

The process of constructing the consolidated financial statements takes several weeks and includes calculation steps as well as manual steps; we will consider the latter here as instantaneous. The calculation steps correspond to the equivalent of 413177 hours of calculation time, i.e. just over 10 full days on an infrastructure of 1700 cores. However, in reality, the process cannot take place in 10 days on such an infrastructure because of the dependencies between the computing tasks: there are times when there are not enough tasks to occupy the grid.

A fine analysis of the dependencies shows that the critical path duration is 11h30. This duration would be that of the whole computation if an infrastructure of infinite size was available.

Project subject: In order to optimize costs without investing in a very large computing grid that would ultimately be little used, we want to use on-demand resources available in the cloud. To make the most of this, **we want to optimize the execution of the task graph** by searching for :

- The best strategy for switching compute nodes on and off.
- The best scheduling of tasks on the available nodes.

The study will have to take into account the following elements:

1. The dependencies between tasks
2. The duration of the tasks, known in advance
3. The duration of the transfer of results between tasks (only the relevant files will be listed).

It should be noted here that the cost mentioned can be energy as well as financial, and that the two are closely linked: in use, more than half of the cost of owning a computing infrastructure corresponds to the cost of electricity, even in France with nuclear energy. We will make the (very simplifying) assumption that the network has no cost.

Project objective: to provide an optimization application working on two files describing on one hand the task graph (durations and dependencies) and on the other hand the characteristics of the computing infrastructure, and which will provide in output a file describing the infrastructure scheduling (switching on and off nodes) as well as the task scheduling (placement of a task on a node at a given time).

Students will be provided with :

- Documentation describing input and output formats and performance evaluation criteria.
- Examples of graphs and infrastructures
- A REST API (calculation function that can be called directly from the Internet) to evaluate the quality of the proposed solution.
- Access to distributed computing resources

Quarter number

ST7

Prerequisites (in terms of CS courses)

First year courses:

- SG1 common course "Systèmes d'Information et Programmation" (1CC1000)
- ST2 common course "Algorithmique et complexité" (1CC2000)

Courses of the ST:

- ST7 common course "Optimisation" (2CC3000)
- ST7 specific course "Méthodes et algorithmes parallèles pour l'optimisation" (2SC7610)

Others prerequisites:

- Parts of common course "CIP - Convergence, Intégration et Probabilités" (1SL1000)
- Parts of common course "EDP - Equations aux dérivées partielles" (1SL1500)
- Knowledge of linear algebra will also be needed

Syllabus

Main steps of the study:

- Complement of courses in hardware architecture of computer systems, including energy aspects.
- Formalization of the problem and the cost function to be optimized.
- Choice of a meta-heuristic optimization method adapted to the problem, examples: genetic algorithms, ant colonies, variable neighborhood method...

- Handling of remote computing resources (in cloud or supercomputer on which ANEO has access).
- Design of an algorithm parallel to the chosen optimization method, capable of scaling in terms of size or complexity of the task graph processed.
- Implementation of a parallel Python code supporting the planned scalability.
- Execution of the parallel resolution code on real data sets provided by ANEO, and within the limits of the computational resources allocated to the study.
- Analysis of the quality of the results of the resolution code, the performance of the resolution calculations performed (calculation speed, scalability), and the associated cost from an industrial exploitation perspective.
- The study will end with a report and an oral presentation aimed at evaluating the overall relevance of the solution found and tested, and the management of the quota of calculation resources that will have taken place during the project.

Rmk: The different groups of students will be confronted with different hypotheses on the targeted computing platforms, leading to equally different choices and implementations of optimization methods.

Class components (lecture, labs, etc.)

Part 1 (40HEE) :

- Steps 1 to 4: course additions, formalization of the problem, choice of an optimization method, and handling of calculation resources.
- Steps 5 and 6: first functional parallel implementation of the solving algorithm, small-scale tests.
- Intermediate report and presentation of progress and the work planned in part 2

Part 2 - *final sprint* (40HEE):

- Steps 7 and 8: execution of the resolution algorithm on intensive computing resources, and evaluation of the results obtained and the performance measured.
- Winding up in part 5 for the improvement of the resolution algorithm and its parallel implementation.

1. Final report and full oral presentation

Grading

This project will be evaluated by a midterm talk at the end of part 1 (40HEE), and by a final talk at the end of part 2 (*final sprint* 40HEE). Talks will be done by the entire team, but will lead to individual marks in case of strongly heterogeneous teams.Each talk evaluation will consider the overall quality of the talk, of the slides and of the progress summary. Each talk mark will be 50% of the total mark.

Resources

Teaching staff:

- **A. Rimmel** (CentraleSupélec & LISN)
- **W. Kirschenmann** (ANEO)

Workplace and computing resources:

- Students will work at CentraleSupelec, in a classroom with electrical outlets and reliable wifi Internet access.
- Students will use their laptops to access remote computing resources (cloud or supercomputer on which ANEO has access).
- Final oral exam will take place at CentraleSupelec the last afternoon of the project.

Learning outcomes covered on the course

At the end of this project, students will be able to:

- **Learning Outcome 0 (AA0):** to identify the CPU consuming parts in an optimization chain, and to model the energy cost of a distributed calculation,

- **Learning Outcome 1 (AA1):** to identify optimization methods adapted to the minimization of the execution time of a task graph, and adapted to a large scale parallelization,
- **Learning Outcome 2 (AA2):** to design a parallel algorithm supporting scaling, to implement it and to develop its code on a distributed architecture,
- **Learning Outcome 3 (AA3):** to deploy intensive simulations on remote computing resources
- **Learning Outcome 4 (AA4):** to identify the limits of the study according to the available computational resources
- **Learning Outcome 5 (AA5):** to manage a quota of calculation resources during an intensive calculation campaign

Description of the skills acquired at the end of the course

- **C4:** Have a sense of value creation for his company and his customers
- **C7:** Know how to convince
- C8: Lead a project, a team

2SC7695 – Low cost optimization of acoustic wave propagation code performance

Instructors : **Stephane Vialle**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES, DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **ENGLISH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

Project of the ST7 "High Performance Simulation for Footprint Reduction",
Project topic in partnership with INTEL.
Majors: Computer Science (INFONUM) & Math, Data Sciences (MDS).

Regardless of the type of application running on parallel machines in an HPC (high performance computing) environment, and regardless of their level of efficiency (in terms of performance or energy footprint), we can easily see that the impact of input parameters is generally not negligible. In particular, we can act on :

- the parameters of the parallel algorithm used, such as the size and shape of the domains performing a sub-problem partitioning,
- HPC implementation parameters controlling for example *cache blocking* to reduce data access times,
- parallel application deployment parameters, controlling the process-MPI vs. threads-OpenMP distribution and the placement of these computational tasks to efficiently occupy CPU cores,
- parameters controlling the thread scheduling policy (usually controlled through environment variables).

These different input parameters allow to improve the execution of HPC code on a computing platform. But it remains extremely difficult to understand exactly how the application behaves in the processor architecture and even if we could make the application more efficient by modifying the source code, the dependency on test cases and the execution environment would still be preponderant. In this context where the parameter space can be of important dimension, the use of optimization algorithms appears fundamental to converge towards a global (or at least local) minimum of a cost function expressing the execution time and the energy footprint. We will therefore use optimization methods and algorithms to optimize the operation of an HPC calculation code.

However, each execution of a test case of an HPC application can be long, even on a parallel machine. The parameter space is large and an optimization algorithm can require tens of thousands of executions of the application (or even more). What is achievable on the scale of a computing kernel remains unbearable on the scale of a complete application.

It is therefore necessary to choose optimization methods that do not consume too many experiments, and then to optimize their use to reduce the footprint of the targeted HPC code, without this pre-study consuming too many computing resources! This amounts to **"looking for the least expensive optimization method"** to find an optimum between convergence speed (of the optimization algorithm) and the quality of the minimization of execution time and energy footprint (of the targeted HPC application).

Technical details of the system :

We will start this project from :

1. a high performance computing code (HPC code) that simulates the 3D acoustic wave equation in a homogeneous isotropic finite-difference medium, and runs on multi-core PC clusters (in MPI + OpenMP),
2. a genetic algorithm capable of iterating on many parameters of the HPC code such as: size and shape of domains and *cache blocking*, compilation flags, environment variables, number and placement of threads..., but which remains sequential and limited to a single machine.

The genetic algorithm thus calls successively the acoustic wave simulation code in different configurations, and can only call it in a multithreaded version on one machine (not in a distributed version on a cluster). This allows nevertheless to search for the optimal configuration on each PC, and then to apply it on each PC when running on a cluster of PCs.

The *finite differences* being quite explicit in terms of the number of floating operations, we can easily count the number of points processed or the number of floating operations performed during an execution, and deduce a processing speed in Giga points/s or GFlops/s. We can then try to minimize the simulation time (or maximize the processing speed). We can also dedicate and collect some hardware counters to obtain the exact power consumption of the processor and memory, to study in detail the energy impact of our optimizations.

But a genetic algorithm is a population-based optimization method that is computationally resource-intensive, and the implementation provided uses only one PC. The search for an optimal configuration of the code can therefore be very long and prohibitive. To overcome this limitation we will adopt two approaches:

- Firstly, we will identify optimization methods that are likely to converge in relatively few tests towards an efficient configuration of the HPC code (i.e. leading to fast and low power consumption executions). We will be able to study optimization methods with trajectories (Hill Climbing, Simulated Annealing, Tabu search..., with or without gluttonous behaviour), or other methods with a population less greedy than genetic algorithms (ant colonies...). A very good solution will thus be sought in a rather long time, which would then allow to execute many simulations of very optimized acoustic wave propagations.
- One will then try to experiment an optimization method, or a variant of the one previously experimented, which would converge "very quickly" towards a solution of only "good enough" quality. Such (very fast) optimization could then be integrated into the application in the form of dynamic pre-processing, at the beginning or during execution on parallel machines, and constitute a self-optimization mechanism for the application.

Quarter number

ST7

Prerequisites (in terms of CS courses)

First year courses:

- SG1 common course "Systèmes d'Information et Programmation" (1CC1000)
- ST2 common course "Algorithmique et complexité" (1CC2000)

Courses of the ST:

- ST7 common course "Optimisation" (2CC3000)
- ST7 specific course "Méthodes et algorithmes parallèles pour l’optimisation" (2SC7610)

Others prerequisites:

- Parts of common course "CIP - Convergence, Intégration et Probabilités" (1SL1000)
- Parts of common course "EDP - Equations aux dérivées partielles" (1SL1500)
- Knowledge of linear algebra will also be needed

Syllabus

Main steps of the study :

- Presentation of the provided computing kernel, complementary courses on the methodologies of characterization and acceleration of HPC code (*hardware counters, roofline modeling, NUMA placement, vectorization...*), handling of the remote computing resources of the CentraleSupélec Teaching Data Center with experimentation of the codes provided by INTEL.
- Identification of promising optimization methods for the problem, and not launching too many HPC simulations of acoustic waves. The development of hybrid methods could be considered.
- Development of a 1st solution in sequential Python with call of the simulation C code provided for the study.

- Development of a first optimization-simulation campaign on multi-core machines, with management of a weekly quota of calculation hours. Identification of a solution that best reduces the footprint of the HPC acoustic wave simulation code.
- Development and experimentation of a 2nd solution, allowing to search "very quickly" for a "good enough" quality configuration, in order to integrate this search into the simulation application at the pre-processing stage.
- Development of a second optimization-simulation campaign on multi-core machines, with management of a weekly quota of calculation hours.
- The study will end with a report and an oral presentation to evaluate:
  - the investigative approach adopted,
  - the quality of the solution found: in terms of the speed of convergence of each optimization algorithm tested, and the computation time and energy consumption of the optimized parallel simulation,
  - the management of the quota of calculation resources that will have taken place during the project.

Rmk: The different groups of students will implement different optimization methods.

Class components (lecture, labs, etc.)

Part 1 (40HEE) :

- Steps 1 and 2: Complementary lectures on HPC code optimizations and on the configuration parameters of the simulation code provided, handling of the remote computing resources of the Teaching Data Center with experimentation of the initial solution, and identification of two promising optimization methods.
- Step 3: sequential implementation in Python of a first optimization method calling parallel simulation code and HPC, first optimization-simulation campaign on a multi-core computing server.
- Step 4: execution of an optimization-simulation campaign on parallel machines, with the management of a quota of hours. Analysis of the obtained performances.

- Intermediate report, and presentation of the progress and the work planned in the 2nd part.

Part 2 - *final sprint* (40HEE):

1. Step 5: identification of a method to search "very quickly" for a "fairly good" configuration. New implementation in Python.
2. Step 6: new optimization-simulation campaign on parallel machines, with the management of a quota of hours. Analysis of the obtained performances.

- Final report and full oral presentation.

Grading

This project will be evaluated by a midterm talk at the end of part 1 (40HEE), and by a final talk at the end of part 2 (*final sprint* 40HEE). Talks will be done by the entire team, but will lead to individual marks in case of strongly heterogeneous teams.Each talk evaluation will consider the overall quality of the talk, of the slides and of the progress summary. Each talk mark will be 50% of the total mark.

Resources

Teaching Staff:

- **S. Vialle** (CentraleSupelec & LISN), G. Quercini (CentraleSupelec & LISN), **H. Talbot** (CentraleSupelec & CVN)
- **Ph. Thierry** (INTEL)

Workplace and computing resources:

- Students will work at CentraleSupelec, in a classroom with electrical outlets and reliable wifi Internet access.
- Students will use their laptops to connect to remote PC clusters at Data Center for Education of CentraleSupelec
- Final oral exam will take place at CentraleSupelec the last afternoon of the project.

Learning outcomes covered on the course

At the end of this project, students will be able to:

- **Learning Outcome 0 (AA0):** to identify the parameters impacting the execution of a parallel code, and to configure its execution,
- **Learning Outcome 1 (AA1):** to choose and configure optimization methods converging with a limited number of experiments,
- **Learning Outcome 2 (AA2):** to develop a sequential Python code, calling parallel codes on parallel architectures,
- **Learning Outcome 3 (AA3)**: to deploy intensive simulations on remote computing resources,
- **Learning Outcome 4 (AA4)**: to identify the limits of the study according to the available computational resources
- **Learning Outcome 5 (AA5):** to manage a quota of calculation resources during an intensive calculation campaign.

Description of the skills acquired at the end of the course

- C4: Have a sense of value creation for his company and his customers
- C7: Know how to convince
- C8: Lead a project, a team

ST7 - 77 - EFFICIENCY OF ON-BOARD ENERGY SYSTEMS

Dominante: ENE (Energy)

Langue d'enseignement : French

Campus : Paris-Saclay

Engineering problem

The optimization of embedded energy systems is a problem encountered daily in the industrial world.

Whether the objective is to reduce production or usage costs, or to participate in the energy transition by minimizing the carbon footprint, optimization is essential in the energy world.

Volume, cost (optimal design or operating cost), performance or efficiency gains are objectives that can be found in aeronautical, space or automotive systems. The system and multiphysics aspect of the design is now taken into account in order to best meet increasingly demanding specifications.

During this sequence, industrial examples will be discussed: optimization of the efficiency and cost of an electric drive train on a few operating points or on road cycles, optimal management of energy sources in a hybrid system.

Adviced prerequisites

It is adviceed to have taken the course "Electrical Energy".

Context and issue modules : These modules include an introductory conference on the theme, a round table involving the partners in the sequence, presentations on the technological and scientific obstacles, and an innovation workshop.

Specific course (60 HEE) : Optimization of embedded energy systems

Brief description:

After a description and formulation of the problem and a presentation of the models related to optimization, the techniques of optimization of energy systems, stochastic optimization, parameter estimation, multi-source optimization and multi-criteria optimization will be examined.

Project n°1 : Energy efficiency of electrical machines

Associated partner: Leroy-Sommer

Location: Paris-Saclay

Brief description :

The problem of energy optimization of electrical machines is posed on the one hand by a search for lower costs of use but also by the regulation which imposes increasingly high yields to control the electrical demand.

It is therefore necessary to optimize the efficiency of electrical machines. Of course, this maximization of the efficiency goes against another optimization: that of the manufacturing cost. A multi-criteria optimization between efficiency and cost will therefore be implemented.

Project n°2 : Optimization of the traction chain on road cycle

Associated partner :

Location: Paris-Saclay campus

Brief description :

The increase in the price of fossil fuels as well as environmental constraints are pushing the automotive and mobility sector to turn more and more to electric traction as a replacement or complement to the combustion engine.

The electric motor in the vehicle is not used on a single operating point as it is the case for a static application, but must respond to the solicitations of driving. To model these behaviors, numerous road test cycles are used. The optimization of the powertrain as a system is made complicated and expensive by the large number of operating points generated by these cycles. Reduction techniques will therefore be used to optimize the yields or the masses of the systems.

Project n°3 : Optimal management of a hybrid generator

Associated partner :

Location: Paris-Saclay campus

Brief description: An energy production generator converts a source into energy. A generator is said to be hybrid when there are several sources available (in the electric case, it can be a battery and a thermal engine and alternator). The choice of the primary energy source is therefore made at the time of use.

On an operating cycle (power demand curve for example), it is necessary to find the optimal set point leading to the best management of the hybrid generator: to know if the electricity is produced from the battery or from the thermal generator.

An optimization is therefore necessary to reduce the operating costs or to increase the efficiency. Subsequently, an optimization of the system according to this optimal management is possible.

Project n°4: Optimization of a naval propulsion chain on cycle

Associate partner: DCNS

Location: Paris-Saclay campus

Brief description: 90% of world trade is carried out by sea. As a result, maritime transport is one of the main contributors to air pollution: 3% of total greenhouse gas emissions in the world. Naval electric propulsion is one of the candidates to replace conventional thermal propulsion systems.

In an electric ship, gas turbines or diesel generators produce electricity that is then used to power both the electric propulsion motors and auxiliary loads. The electrical system on board can be AC or DC. Such a system must be optimized to minimize its cost and maximize its efficiency. In particular, if the vessel follows a fixed route (such as a ferry), the optimization can take into account the operating cycle.

2SC7710 – Numerical methods and problem solving for optimizing embedded energy systems

Instructors : **Maya Hage Hassan, Philippe Dessante**
Department : **DÉPARTEMENT SYSTÈMES D'ÉNERGIE ÉLECTRIQUE**
Language of instruction : **FRENCH**
Type of course : **Specific course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

The optimisation of on-board energy systems is a problem encountered daily in the industrial world. Whether the aim is to reduce production or operating costs, or to contribute to the energy transition by minimising the carbon footprint, optimisation is essential in the world of energy.

Volume, cost (optimal design or operating cost), performance or efficiency gains are all objectives that can be found in aeronautical, space or automotive systems. The system and multiphysics aspects of design are now taken into account in order to best meet increasingly demanding specifications.
During this sequence, industrial examples will be approached via projects: optimisation of the efficiency and cost of an electric drive train on a few operating points or on road cycles, optimal design of electric actuators, dimensioning of converters for on-board systems, design of naval and aeronautical drive trains, dimensioning of an electric bicycle.

Course outline (content)

1) Definition of the design activity
2) Problem formulation
3) Solving the problem: deterministic or stochastic methods
4) Reformulation: Multi in single objective, and with/without constraints

5) Practical work: multiphysics modelling of a transformer, optimisation (reformulation with SQP) and NSGA-II
6) Assessment of skills (C6,C2): 3 hours of independent work in a compulsory room, CR to be handed in at the end of the session.

7) Eco-design

As part of this thematic sequence, we are proposing projects under three themes:

Energy efficiency // Partners WattandWell, SafranTech, GeePs
Optimal network management // Partner SRD energies, GeePs
Optimising a propulsion chain // GeePs

You are invited to choose the project that interests you most under each theme. At the end, you will be allocated a single project.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Electrical Energy
Transport Phenomena

Syllabus

Problem formulation
Models related to optimization
Optimization of energy systems
Stochastic optimization (simulated recruit, genetic algorithms, differential evolution)
Parameter estimation
Dynamic programming
Multi-source optimization
Multi-criteria optimization

Class components (lecture, labs, etc.)

Lectures
TD/TP : 9h
Skills evaluation : 3h

Grading

Written exam : 1h30

Evaluation of the practical work
Skills evaluation

Course support, bibliography

Course presentations
Matlab files

Resources

Lecture, TD, TP, Skills assessment, Project

Learning outcomes covered on the course

Optimization
Systems
Optimization of embedded systems
Stochastic optimization

Description of the skills acquired at the end of the course

The student will be able to implement an optimization of an embedded system.
- problem formalization
- mathematical optimization
- results analysis
- multi-objectives

2SC7790 – Efficiency of on-board energy systems

Instructors : **Philippe Dessante, Maya Hage Hassan**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRENCH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

ST7 - 78 - ENERGIE TRANSITION IN ISOLATED SITES

Dominante **:** GSI (Large Interacting Systems), ENE (Energy)

Langue d'enseignement **:** English

Campus où le cours est proposé **:** Rennes

Engineering problem

This topic focuses on the problems associated with a transition to a more just and sustainable world in terms of access to energy. Indeed, some sites, houses or others, are not and cannot be connected to the distribution network because of the technical complexity of connection and extension of the network or because the cost of such an operation is either not justified or is not feasible for areas located in poor regions of the world. It is therefore necessary to propose solutions based on the development of microgrids. Microgrids allow the local deployment of small-scale collective installations thanks to hybrid systems with decentralized production and storage as well as intelligent management of production, storage and demand for each user.

The deployment of microgrids requires a system approach where the following questions arise:

- how to manage a multi-component system subject to different constraints,

- how to manage and take into account the multiplicity of stakeholders: users, communities, financiers, standards, etc.

- how to manage the trade-off between economic cost, environmental impact on life cycle, and quality of service.

Throughout the thematic sequence (context and issues modules, specific course, project) students will address these issues. They will be interested in defining the need for a given situation, in modeling and formalizing the optimization problem. They will be led to propose technically and economically reliable solutions in an uncertain environment.

Adviced prerequisites

Modeling, Probability/Statistics course

Context and issue modules:

These modules include an introductory lecture on the theme, presentations on the technological and scientific challenges, and a presentation of the associated projects.

Specific course (60 HEE) : Renewable energies and microgrids

Brief description :

Faced with the negative environmental impacts of all energy production and the depletion of fossil resources, the transition to renewable sources is a fundamental trend. While renewables provided only 25% of global electricity production in 2018, this share is growing rapidly, with wind and solar tripling over 10 years.

These new energies raise specific questions that this course proposes to address:

- what are the wind and solar energy sources and the main principles of their conversion into electricity?

- What are the storage technologies, in particular batteries, capable of handling the variability of these sources?

- What are the technical, environmental and economic challenges of these technologies?

Moreover, wind and solar power are much more decentralized sources than traditional thermal power plants. Thus, the production of electricity is closer to the places of consumption, which gives rise to the notion of "microgrid", analogous to the short circuits in agriculture.

A microgrid is a small electrical system that integrates production and consumption in a defined area (building, district, island, etc.) and is equipped with local management of energy flows. A microgrid can be autonomous or connected to a large network. If it is connected, it behaves as a single, intelligent player, capable, for example, of buying electricity from the wholesale market at the best times or providing network services. The integration of all these components and functions poses system optimization questions addressed in this course.

Due to their small size, reliability is an important issue for microgrids. This course proposes to study the methods of dependability to analyze the risks of failure, plan maintenance and react to failures...

Project: Decarbonized island microgrid

Associated partner:

Location: Rennes campus

Brief description :

Nearly one billion people still do not have access to electricity (IEA 2018). These populations are often in remote areas in rural or island regions. Thus, for 3/4 of them, it is not economically efficient to bring electricity to them by expanding existing large-scale power grids. Electrification must therefore be done on a local scale, through what are known as microgrids.

The generation of electricity in a microgrid can be done by fossil fuels (diesel generators) or by renewable energies (solar panels...). Thanks to technological progress, the latter are generally less expensive. However, their intermittency pushes to complete them by more expensive but controllable means (Diesel, battery storage, hydrogen...). The size of each of the components of a microgrid (called its "dimensioning") must therefore be optimized according to various criteria: economic cost, of course, but also quality of service, energy independence or greenhouse gas emissions. The management of energy flows (e.g.: arbitration between diesel and battery/hydrogen) is also to be optimized. This project proposes to address these different optimization issues on the concrete case of isolated sites.

2SC7810 – Renewable energies and micro grids

Instructors : **Pierre Haessig, Nabil Sadou**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Specific course**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

Faced with the negative environmental impacts of any energy production and the depletion of fossil resources, the transition to renewable sources is a profound trend. While renewable energies provided only 25% of the world's electricity production in 2018, this share is growing rapidly, with a threefold increase over 10 years in wind and solar energy.

These new energies raise specific questions to be addressed in this course:

- What are the wind and solar resources and the main principles of their conversion into electricity?
- What are the storage technologies, in particular batteries, that can manage the variability of these sources?
- What are the technical, environmental and economic challenges of these technologies?

In addition, wind and solar energy are much more *decentralized* than conventional thermal power plants. Thus, electricity production is moving closer to consumption areas, which leads to the emergence of the notion of "microgrid", similar to short food supply chains (SFSCs).

A microgrid is a small electrical system that integrates production and consumption within a delimited area (building, district, island, etc.) and is equipped with a local energy flow management system. A microgrid can be stand-alone or connected to a large network. If connected, it acts as a unique and intelligent actor, able, for example, to buy electricity from the wholesale market at the best moments or to provide grid services. The integration of all these components and functions raises system optimization issues that are covered in this course.

Due to their small size, the issue of reliability is an important one for microgrids. This course aims to study the methods of *dependability* to analyze the risks of failure, plan maintenance and react to outages…

Quarter number

ST7

Prerequisites (in terms of CS courses)

None

Syllabus

Renewable energies (REn) and storage :

1. Solar, wind, hydroelectric, bio-mass,...
2. Modeling and predictability of production
3. flexibility, storage technologies

Micro grids :

- Electrical grid architecture and modeling
- Sizing and operational management: taking into account the impacts of renewable energies, Quality of Service (voltage, frequency, etc.)

Reliability of grids:

- Reliability indicies
- Security bdies
- Reconfigurability
- Failure and reliability of components

Economic models of micro grids:

- Investment plan, profitability
- Uncertainties and risk management
- Energy markets, price signal, trading

Class components (lecture, labs, etc.)

Lecture (~50%): Exercise/labs (~50%)

Grading

written examination 1h30 - (70%) continuous assessment (30%)

Resources

lecture, labs.
This course contains lectures and a large part of labs.

Learning outcomes covered on the course

At the end of this course, students will be able to :

- Understand the economical, ecological and societal context of microgrids
- Identify and characterize the different energy production sources and energy storages.
- Size a microgrid with different energy sources and energy storage, taking into account technical/non-technical constraints and uncertainties.
- evaluate system performances and system dependability.

Description of the skills acquired at the end of the course

- Understand the economical, ecological and societal context of microgrids. C1.1
- Identify and characterize the different energy production sources and energy storages C2.1
- Size a microgrid with different energy sources and energy storage, taking into account technical/non-technical constraints and uncertainties. C2.1

2SC7890 – Insular carbon-free micro grid

Instructors : **Pierre Haessig, Nabil Sadou**
Department : **DOMINANTE - ENERGIE, DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **ENGLISH**
Type of course : **Project ST7**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

Nearly 800 million people are still without access to electricity (IEA 2021). These populations are often found in isolated regions in rural or insular areas. Thus, for 3/4 of them, it is not economically efficient to bring them electricity by expanding the existing large electricity networks. Electrification must therefore be done at the local level, through microgrids.

The generation of electricity in a microgrid can be done using fossil fuels (diesel generators) or renewable energies (solar panels...). Thanks to technological advances, the latter are generally cheaper. However, their intermittency pushes to supplement them with more expensive but controllable means (diesel, battery storage...). The size of each of the components of a microgrid (called its "sizing") must therefore be optimized according to different criteria: the economic cost of course, but also the quality of service, energy independence or greenhouse gas emissions. The management of energy flows (e.g.: arbitrage between diesel and battery) also needs to be optimized. This project proposes to address these different optimization challenges in the real case of an isolated island site.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Optimization course.

Syllabus

Problem definition :
Input data:
- collection of production and consumption data
- data analysis and normalization

Modeling and formalization:
- definition of optimization criteria
- formalization of the optimization problem

Resolution:
- choice of resolution method
- sensitivity analysis

Class components (lecture, labs, etc.)

Project 80HEE

Grading

project reports and presentations (intermediate and final)

Resources

project in groups

Learning outcomes covered on the course

By the end of this course students will be able :

- Understand the economic, ecological and societal context and challenges of microgrids.
- Formalize an optimization problem
- Select the appropriate resolution method.
- Trade-off analysis
- Work in groups and results present

Description of the skills acquired at the end of the course

1. Understand the economic, ecological and societal context and challenges of microgrids. C1.1, C.4.2
2. economical et technical microgrid modelling C2.1, C6.2
3. Formalize an optimization problem. C1.2, C1.3, C2.1
4. Select the appropriate resolution method. C2.1, C2.3, C6.1, C6.2
5. presentation of the results. C7.1
6. Work in groups. C8.1, C8.4

ST7 - 79 - DIGITAL TECHNOLOGY AT THE SERVICE OF THE HUMAN FACTOR

Dominante: Info&Num (Computer Science & Digital), MDS (Mathematics, Data Sciences), VSE (Living-Health, Environment)

Langue d'enseignement : French

Campus : **Rennes**

Engineering problem

The massive recourse to computer automation of numerous processes, to AI-type decision-making agents, and to the analysis of ever larger data sets, question the relationship between humans and information technologies.

In fact, the current speed of development of these technologies, and the wealth of tools that are emerging, allow us to get even closer to the human being. Analysis of expressions and emotions by extraction of multi-sensor data (webcam, kinect, micro, EEG, sweating), modeling of human behavior in critical contexts (crisis, health problems, depression) and advanced analysis of interactions between different agents, are all possibilities offered by digital tools.

For research in the humanities and medicine, these new methods represent an opportunity to refine our understanding of subjects, patients and their relationship to the world or to others (autistic behavior, collaborative contexts).

The CentraleSupélec engineer will be able to understand how to put digital technology at the service of the human factor, what its possibilities and limits are, and which technologies are appropriate for building the computer science of tomorrow.

Adviced prerequisites

Courses in Algorithms and Complexity, Statistics and Learning, Signal Processing

Context and issue modules:

These modules include an introductory lecture on the theme, presentations on the technological and scientific challenges, and a presentation of the associated projects. The whole will allow to highlight a common problem (the analysis of non-verbal behavior) with very varied application fields, and will give an introduction to social psychology, on the aspects of verbal and non-verbal language.

Specific course (60 HEE) : 2D-3D Image and Sound Analysis

Brief description: the course will cover three important parts necessary for project completion:

Image analysis: Filtering, segmentation, feature detection

Sound analysis : time-frequency representation, speech modeling, spatial audio

Project: What you say without meaning to: deciphering and automatic analysis of non-verbal behavior

Associated partner :

Location: Rennes

Brief description: Every year, the audio, video and machine learning communities gather around international research challenges on the automatic analysis of human behaviors: emotions, depression, mood, motion detection, etc. (e.g. http://sspnet.eu/avec2017/). The project consists in the participation to one of these challenges. It is about, from a large corpus of data representing subjects in action, to automatically determine information about their behavior and emotions.

Each project team will focus on a particular study (e.g. voice, face, etc.), knowing that all the teams will participate in the same international challenge.

It will therefore be necessary to choose and apply certain methods seen in the course of image and 3D sound analysis. The classification and regression tools will lead to the implementation of optimization algorithms (neural network regression, fuzzy logic, SVM,...).

2SC7910 – 2D-3D image and sound analysis

Instructors : **Gwendal Fouché**
Department : **CAMPUS DE RENNES**
Language of instruction : **ENGLISH**
Type of course : **Specific course**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

Sight, hearing, touch, smell and taste. It is through our 5 senses that we apprehend our environment and interact with it. In recent years, living beings are no longer the only ones who interact and understand the world around them. More and more powerful automatic image and sound analysis tools are created every day. Whether for autonomous driving, space, medical, the fields of application are multiple. And more recently, these techniques have gained new momentum with Deep Learning and generative models. It is now difficult to recognize a true picture of a fake picture And it becomes easy to make artificially but effectively say whatever you want to whoever you want.
In this module, you will discover an overview of analysis and synthesis techniques for 2D and 3D image and sound, through precise use cases. You will be the actors of the understanding and the artificial modification of your environment!

Quarter number

ST7

Prerequisites (in terms of CS courses)

Statistics et machine learning.
Signal processing
Computer science :

- Algorithms
- Programming langages

Syllabus

Background (5%)

1. Introduction to the subject
2. Historical context.
3. Link with the subjects of the program.

Image Analysis (35%)

- Filtering: low-cut filter, high-pass filter, Canny filter
- Segmentation: waterShed, Split & merge, region growing
- Feature extraction: LBP, SIFT, HOG

Sound analysis (35%)

- Audio signals and time-frequency representation
- Speech production and modeling
- Spatial audio

Synthesis of image and sound (10%)

- 3D image synthesis: from basics to animation
- Stereoscopy

Personal study (15%)

- Choosing a subject
- Exploration and presentation

Class components (lecture, labs, etc.)

- Applied course : mixing theory and practice : 50% (30 HEE)
- Evaluation : 10% (6 HEE)

- Applied course reports, and personal study : 40% (24 HEE)

Grading

MCQ of theoretical knowledge: 1/3 of the note

Defense of the project of realization of an applied course : 1/3 of the note
Applied course content and justification: 1/3 of the note

Course support, bibliography

For audio, videos available online: https://www.animations.physics.unsw.edu.au/waves-sound/oscillations/index.html
For image synthesis: OpenGL Programming Guide

Resources

Teaching team:

- Catherine SOLADIE
- Renaud SEGUIER
- Simon LEGLAIVE
- Gwendal Fouché
- PhD Students of AIMAC research team
- Externals

Software tools and number of licenses needed:

- Python libraries
- Anaconda and Jupyter Notebooks
- OpenGL

Learning outcomes covered on the course

By the end of the course, you will be able to :

1. Cite many techniques for extracting audio and video characteristics (C2.1)
2. Choose the relevant treatment for the analysis, understanding and synthesis of audio and video data (C6.1)
3. Design, implement and validate a complete audio and / or video processing system (C2.1 et C6.1)
4. Understand and explain new algorithms in image and sound processing (C7.4)

Description of the skills acquired at the end of the course

- C2 Jalon 2
    - C2.1 **Approfondissement** : Approfondir l'ensemble de ses connaissances sur un domaine choisi, via les enseignements de 2A
- C6 Jalon 2
    - C6.1 **Numérique :** Résoudre numériquement un problème
- C7 Jalon 2
    - C7.4 **Convaincre sur les techniques de communications** : Déployer avec succès des techniques de communication adaptées à la situation spécifique, parmi lesquelles : rhétorique, storytelling, langage corporel, occupation d'espace, respiration, mémoire, supports visuels, outils vidéos, distanciel, etc…

2SC7990 – What you unwittingly say: decryption and automatic analysis of nonverbal behaviors

Instructors : **Gwendal Fouché**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES, DOMINANTE - INFORMATIQUE ET NUMÉRIQUE, DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT**
Language of instruction : **ENGLISH**
Type of course : **Project ST7**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

What you unwittingly say: decryption and automatic analysis of nonverbal behaviors.

Letters, words, sentences: the algorithms we have today are more and more effective in decrypting our grammar, and understanding what we can say. And yet this only covers a tiny part of our communication.

Joy, resignation, irony: only our body and the tone of our voice reveal our deep intentions, our real message, and the automated understanding of such human behaviors and emotions is a big challenge.

To take it up, every year, the audio, video and machine learning communities gather around international challenges of research on the automatic analysis of human behaviors: emotions, depression, mood, motion detection, ... (ex: http://sspnet.eu/avec2017/).

Through this project, you will be able to face one of these challenges. You will have a large dataset representing people in action and will have to automatically determine their behavior and emotions.

Each project team focuses on a particular study (eg the voice, the face, ...), and all teams will gather their work to compare your results to those of the competitors of the international challenge.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Statistics et machine learning.
Signal processing
Computer science :

- Algorithms
- Programming langages (basics)

Syllabus

Background (5%)

1. Introduction by the research team.
2. Group organization.

3. Provision of the challenge data.

State of the art (20%)

- Research and understand research papers on the subject.
- Reproduce a selected subset of state-of-the-art methods (they will serve as a basis for your work).

Pre-processing, understanding and visualization of data (40%)

- Depending on the chosen topic (voice, face, ...), extract the interesting features for your analysis
- Explore the relevant visual representation modes
- Use these representations to guide your analysis strategy

Statistical analysis and learning (20%)

- Choose and build your analysis and learning models
- Quantify your results and compare them to the state of the art

Visibility points and final presentation (15%)

- 3 daily feedback will have to be carried out to present your progress as the project progresses (a different member of the team each time).
- Structure your presentations with the objectives, the state of the art, the architecture diagram, the results tables.
- At the end of the project, present as a team your results to our industrial and academic partners.
- Provide a scientific report

Class components (lecture, labs, etc.)

- Immersion in the AIMAC research team: supervision by researchers, PhD students and post-docs.
- Organization in teams of 2 to 5 students. If possible, coordination of the different teams for the production of a single overall final result.
- Presentation of the results to our partners.

Grading

Individual daily feedback: 1/4 of the mark
Defense in front of the partners: 1/4 of the mark
Scientific results (system performance): 1/4 of the mark
Scientific report: 1/4 of the mark

Resources

Teaching team:

- Catherine SOLADIE
- Renaud SEGUIER
- Simon LEGLAIVE
- Gwendal Fouché
- PhD students of AIMAC research team

Software tools and number of licenses needed:

- TensorFlow or equivalent (free)

Learning outcomes covered on the course

At the end of this project, you will be able to:

- Specify or redefine the need (C4.1)
- Navigate among the research papers of a subject, read them and understand them (C2.4)
- Reproduce a selected subset of state-of-the-art methods in signal processing and / or machine learning (C3.2)
- Mix skills from signal processing, statistical analysis and machine learning to analyze data (C2.2)
- Explore visual representation modes that are relevant to your data (C6.3)
- Use these representations to guide your analysis strategy (C3.3)
- Choose and build your analysis and learning models (C1.2, C6.1)
- Quantify your results and compare them to the state of the art (C2.4, C3.3)
- Conduct a large-scale scientific project in a group (C8.1)
- Decrypt a set of non-verbal messages during human interactions (C7.4)
- Argue your scientific approach (C7.1)

Description of the skills acquired at the end of the course

1. C2 Jalon 2
    a. C2.4 **Données** : Exploiter un ensemble cohérent de données et réaliser un état de l'art exhaustif avec un esprit critique
2. C6 Jalon 2
    - C6.3 **Traiter des données** : Mettre en œuvre des algorithmes traitant ou utilisant des données massives (intelligence artificielle, clustering)
3. C4 Jalon 2
    - C4.1 **Besoin client** : Identifier avec le client les autres dimensions ne figurant pas dans la formulation initiale : techniques, économiques, humaines, etc.
4. C7 Jalon 2
    - C7.1 **Convaincre sur le fond** : Adapter le fond et son argumentation en fonction d'interlocuteurs ou de contextes élargis, « avoir du répondant » pour défendre sa solution (maîtrise du sujet des interlocuteurs, valeurs, engagements, disponibilité, attention, etc.).
5. C8 Jalon 2
    - C8.1 **Travailler en équipe** : Associer chaque membre de l'équipe en fonction de ses forces

ST7 - 80 - SOURCE SEPARATION FOR OPTIMAL SIGNAL PROCESSING

Dominante **:** MDS (Mathematics, Data Science)

Langue d'enseignement **:** French

Campus **: Metz**

Engineering problematic

In order to increase productivity, to reduce ecological impact or to improve the quality of services, manufacturers and research centers must respond to the issues of data analysis made up of overlapping signals. Indeed, in many applications, sensor signals are mixtures of several sources that emit at the same time, and the information carried by these signals can only be exploited if we manage to separate what comes from each source. For example, in oil exploration, companies are now carrying out acquisition campaigns in simultaneous source mode (several sources emit at the same time). It is then necessary to distinguish in the signals of the geophones the echoes due to the various sources to obtain an image of the subsoil. Or in a "hi-tech" store, a robot that has started a conversation with a person may be disturbed by other customers or by ambient noise, while it must continue its conversation with the same person. Or in electrocardiograms, to separate the signal of the fetus' heart from that of its mother. Or for sound recording in a conference or round table with several speakers, rather than giving a microphone to each speaker, it would be practical to separate what each speaker says from recordings of microphones placed in fixed positions. The solutions to these problems are based on the same mathematical concepts:

- The knowledge of a data representation space adapted to the problem, where data have a sparse representation (in other words the data can be represented by a vector which has a few non-zero coordinates, in a space of great dimension);
- the minimization of a criterion that depends on the data; and
- a learning and testing stage to verify that the obtained solution generalizes and thus avoid overfitting.

Necessary prerequisites

First year courses in probability, statistics, signal processing and algorithms; good skills in a programming environment (Matlab, Python, ...).

Context and issues modules: These modules include an introductory lecture on the theme, presentations on environmental and societal issues and on technological and scientific challenges, as well as a presentation of related projects.

Specific course (60 HEE): Sparse representations of signals

Brief description: This course presents the mathematical tools of signal analysis and their properties (complements on the Fourier transform, subsampling/oversampling, harmonic signal, STFT, multiresolution analysis, Paley-Littlewood and bi-orthogonal wavelet decompositions, perfect reconstruction filter banks) as well as signal decomposition methods (Matching Pursuit, Basis Pursuit, Independent Component Analysis).

Projet n°1 : Tracking a speaker by a robot

Associated partner: ORANGE, Cognitive Computing

Campus: Campus de Metz

Brief description: Robots are increasingly present in our environment. When a robot has started a conversation with a speaker, the problem is to keep the focus on the interlocutor while several people are talking around the robot, or another interlocutor is talking to it. ORANGE wants to solve this problem by using a monophonic audio signal recorded by the robot, without adding other modalities.

The issue is therefore to find one or more data representation spaces well adapted to the problem of speaker tracking; to learn from a small number of samples (i.e. over a small recording duration) the features of the speaker

to be tracked; to avoid overfitting which may occur if the learned features depend on the words spoken by the speaker.

Projet n°2 : Separation of sound sources from recordings of several microphones

Associated partner: CentraleSupélec, audio plateform of the « smartroom

Campus: Campus de Metz

Brief description: There are many concrete situations in which you want to capture a sound so you can either record it for replay or amplify it live so that all participants have a good perception. Dans certaines de ces situations, plusieurs sources peuvent intervenir (par exemple, une conférence ou table ronde dans laquelle plusieurs locuteurs sont présents).

In order to allow good intelligibility in the case of several speakers, a microphone is usually placed in front of each speaker, or, in the theater, a radio transmitter microphone is placed directly on the actors. A significant improvement could be to use a fixed microphone array and to have a processing algorithm to separate the sources, thus giving the illusion of having an individual microphone per speaker or actor.

The problem is therefore, starting from a fixed microphone array and assuming a finite number of sources (e.g. speakers), to ensure the separation of the sources and to provide an output channel per source (speaker), which channel would also contain the position information of this source. For simplicity, we will start by assuming that the speakers are at fixed positions known in advance. This is the case, for example, for speakers at a round table. In this case, the system could be calibrated beforehand using white noise generators, and then could operate using the fixed parameters determined in this way.

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Projet n°3 : Non-invasive foetal electrocardiogram extraction

Associated partner: INSERM

Campus: Campus de Metz

Brief description: Non-Invasive foetal electrocardiography (NI-FECG) represents an alternative foetal monitoring technique to traditional Doppler ultrasound approaches, that is non-invasive and has the potential to provide additional clinical information. However, despite the significant advances in the field of adult ECG signal processing over the past decades, the analysis of NI-FECG remains challenging and largely unexplored. This is mainly due to the relatively low signal-to-noise ratio of the FECG compared to the maternal ECG, which overlaps in both time and frequency.

The issue is to find one or several data representation spaces well adapted to the problem of foetal ECG extraction. It will be a question of applying and testing one or several methods starting from an article that reviews recent advances in NI-FECG research including: publicly available databases, NI-FECG extraction techniques for foetal heart rate evaluation and morphological analysis, NI-FECG simulators and the methodology and statistics for assessing the performance of the extraction algorithms..

2SC8010 – Sparse representations of signals

Instructors : **Stephane Rossignol**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Specific course**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

The parsimonious representation of signals is one of the fundamental concepts in data science. Parsimonious representations make it possible to represent complex signals (such as sounds) by a small number of non-zero coefficients, this in very large spaces. They thus make it possible to find structures or regularities in very large spaces. These representations are at the heart of the mathematical understanding of the effectiveness of recent algorithms and techniques of supervised or unsupervised learning and scattering transformations.

The lecture introduces some mathematical tools used in signal analysis and their properties (complements about the Fourier transform, subsampling, oversampling, harmonic signal, STFT, multi-resolution analysis, Paley-Littlewood wavelet decompositions, and bi-orthogonal analysis, perfect reconstruction filter banks) as well as signal decomposition methods (Matching Pursuit, Basis Pursuit, Independent Component Analysis).

Quarter number

ST7

Prerequisites (in terms of CS courses)

Probability, statistics, signal processing (1CC4000 and 1CC5000) and first year algorithmic lectures (1CC1000); a good knowledge of a programming environment (Matlab/Octave, Python).

Syllabus

Harmonic analysis: reminders and complements on the Fourier transform (under/over-sampling, DFT, filter banks, harmonic signal, Hilbert transform, short term Fourier transform (STFT)).

Multi-resolution analysis: Paley-Littlewood wavelet decomposition, bi-orthogonal, perfect reconstruction filter banks.

Decomposition of a signal: dictionary, parsimonious representation, matching pursuit, orthogonal matching pursuit, basis pursuit.

Independent component analysis: notions of entropy, entropy rate of a random signal, mutual information, independent component analysis (ACI), ACI in an orthonormal basis, blind deconvolution.

Concepts of supervised learning: introduction to basic notions of learning, test basis, over-learning, empirical risk, real risk (or generalization).

Class components (lecture, labs, etc.)

17.5h Lecture
9h Tutorials

8h Labs. A single topic.

Grading

Continuous monitoring (50%, 2/3 MCT at the beginning of the tutorials; individual score) and oral presentation at the very end of the labs (50%). Labs : grading by pair; differentiated in the event of an anomaly in a pair.

Course support, bibliography

A wavelet tour of signal processign, Stéphane Mallat
https://www.di.ens.fr/~mallat/papiers/WaveletTourChap1-2-3.pdf

Resources

Teacher : Stéphane Rossignol
Room size for tutorials : 34
Max room size for labs : 34

Software : Matlab (34 licences)/Octave (Python)

Rooms for labs : rooms on Metz campus

Learning outcomes covered on the course

- Being able to design a complete signal processing chain.
- Being able to compare the performances of the various tools at our disposal for the analysis of complicated time series, in order to choose the one which will be best suited for this or that signal to be analyzed.
- Being able use correctly the basic and advanced principles of analog signal processing and digital signal processing.

Description of the skills acquired at the end of the course

C2. Develops in-depth skills in an engineering field and a family of professions.

C6. Be operational, responsible, and innovative in the digital world.

2SC8092 – Tracking a speaker by a robot

Instructors : **Michel Barret**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRENCH**
Type of course : **Project ST7**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

The project, which is part of the ST7-Optimization "Source separation for optimal signal exploitation", will focus on a problem of source separation posed by a client partner: ORANGE, Cognitive Computing in Arcueil.

Robots are increasingly present in our environment. When a robot has started a conversation with a speaker, the problem is to keep the focus on the interlocutor while several people are talking around the robot, or another interlocutor is talking to it. ORANGE wants to solve this problem by using a monophonic audio signal recorded by the robot, without adding other modalities.

The issue is therefore to find one or more data representation spaces well adapted to the problem of speaker tracking; to learn from a small number of samples (i.e. over a small recording duration) the features of the speaker to be tracked; to avoid overfitting which may occur if the learned features depend on the words spoken by the speaker.

Quarter number

ST7

Prerequisites (in terms of CS courses)

- Probability 1A (CIP-EDP, 1SL1000),
- Signal processing ST4 (1CC4000)
- Statistics, Machine learning and Data processing ST4 (1CC5000),
- Digital environment, computer and programming SG1 (1CC1000).

Syllabus

Proposed solution: The space of scattering coefficients, obtained by scattering transforms, seems well adapted to the problem of tracking an unknown interlocutor from a speaker recording of short duration. The scattering transformations, based on the wavelet decompositions, depend on meta-parameters that must be adjusted. A heuristic recommends adjusting them to have a more "sparse" representation of transformed coefficients. Different classifiers (linear, SVM, other?)wWill have to be tested in supervised learning to better separate speakers in the space of the scattering coefficients.

Other approaches are possible (convolutional neural networks on raw data or separation in the MFCC --- Mel-Frequency Cepstral Coefficients) --- representation).

We will try to split the problem into sub-systems and try to treat a part of it well and/or to evaluate speaker separation algorithms for which implementations are available on the net.

Class components (lecture, labs, etc.)

This teaching is in the form of a project.
For the duration of the project, students will be asked to keep a "laboratory notebook", specifying in a few lines for each experiment or test carried out, its motivations, the results obtained, the source codes and the data used.
During the last week dedicated to the project, students will be asked to:

1. provide the project report; and
2. to carry out the defense in the presence of the partner.

A progress report of the project with reading of the "laboratory notebook" and the draft report will take place regularly.

Grading

The project will be assessed:

- in continuous control at the advancement points, the "laboratory notebook" reading and the draft report reading (individual note CC);
- during the final defense (individual note S).

In addition, the quality of the deliverables: final report, "laboratory notebook" and commented source codes, will be evaluated (note QL).

Final score = CC/3 + S/2 + QL/6.

In case of a justified absence to one of the intermediary examinations, the grade of this latter is replaced by the grade of the final defense.

The evaluation of skills is specified in the paragraph "description of acquired skills".

Course support, bibliography

Y. Luo & N. Mesgarani, "Conv-TasNet: Surpassing Ideal Time-Frequency Magnitude Masking for Speech Separation", *IEEE Transactions on Audio, Speech and Language Processing*, vol. 27, no. 8, pp. 1256 - 1266, August 2019.
C. Subakan, M. Ravanelli, S. Cornell, M. Bronzi, J. Zhong, "Attention is all you need in speech separation", *Proceeding of IEEE International Conference on Acoustics, Speech and Signal Processing* (ICASSP), pp. 21-25, June 2021.

Resources

80 HEE of project

Learning outcomes covered on the course

At the end of this course, students will be able to:

- represent and decompose audio signals in an "optimal" way ;
- fit a model to data ;
- use a programming language to efficiently write a data processing algorithm.

Description of the skills acquired at the end of the course

C4: Have a sense of value creation for the company and its customers (assessed during project monitoring)
C6: Be operational, responsible and innovative in the digital world (evaluated throughout the project)
C7: Know how to convince (evaluated during the follow-up, at the defense and in the deliverables)
C8: Lead a project, a team (evaluated by the laboratory notebooks)

2SC8093 – Separation of sound sources from recordings of several microphones

Instructors : **Jean-Louis Gutzwiller**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRENCH**
Type of course : **Project ST7**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

This project, which is part of the thematic sequence 7 "Source separation for optimal signal exploitation", focuses on the separation of multiple sources in audio signals.

There are many concrete situations in which you want to capture a sound so you can either record it for replay or amplify it live so that all participants have a good perception.
In order to allow good intelligibility in the case of several speakers, a microphone is usually placed in front of each speaker, or, in the theater, a radio transmitter microphone is placed directly on the actors.
A significant improvement could be to use a fixed microphone array and to have a processing algorithm to separate the sources, thus giving the illusion of having an individual microphone per speaker or actor.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Probability 1A (CIP-EDP, 1SL1000),
Signal processing ST4 (1CC4000)
Statistics, Machine learning and Data processing ST4 (1CC5000),
Digital environment, computer and programming SG1 (1CC1000).

Syllabus

Evaluation of sound processing algorithms using matrix programming language.
Computer development in C / C ++ language of the retained algorithms.

Class components (lecture, labs, etc.)

This teaching is in the form of a project.
For the duration of the project, students will be asked to keep a "laboratory notebook", specifying in a few lines for each experiment or test carried out, its motivations, the results obtained, the source codes and the data used.
During the last week dedicated to the project, students will be asked to:
- provide the project report; and
- to carry out the defense in the presence of the partner.
A progress report of the project with reading of the "laboratory notebook" and the draft report will take place regularly.

Grading

The project will be evaluated in two situations:

- in continuous assessment during the progress points and the reading of the "laboratory notebook" and

provisional report, with individual evaluation of the contributions of each member (CC grade)
- during the final defense (grade S corresponding to the individual presentation of each participant)

and by the quality of the deliverables (final report, commented source codes, laboratory notebooks: grade QL).

The final grade = CC / 3 + S / 2 + QL / 6.

The evaluation of skills is specified in the paragraph "description of acquired skills".

Resources

A network of microphones available in the smartroom of the Metz campus makes it possible to make sound acquisitions. Students will work on computers to develop the computer algorithm to achieve the desired function.

80 HEE of project.

Learning outcomes covered on the course

At the end of this course, students will be able to:
- Represent and decompose audio signals in an "optimal" way
- Adjusting a model to data
- Use a programming language to effectively write a signal processing algorithm

Description of the skills acquired at the end of the course

C4 : Have a sense of value creation for his company and his customers (evaluated during project monitoring)
C6 : Be operational, responsible, and innovative in the digital world (evaluated throughout the project)
C7 : Know how to convince (evaluated during the follow-up, at the defense and in the deliverables)
C8 : Lead a project, a team (evaluated by the laboratory notebooks)

2SC8094 – Non-invasive extraction of the fetal electrocardiogram

Instructors : **Jean-Luc Collette**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRENCH**
Type of course : **Project ST7**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

The project, which is part of the ST7-Optimization "Source separation for optimal use of signals", will focus on a source separation issue raised by a client partner: INSERM in Nancy.

Non-invasive fetal electrocardiography (NI-FECG) represents an alternative fetal monitoring technique to traditional Doppler ultrasound, which is non-invasive. However, despite significant advances in adult ECG signal processing over the past decades, analysis of NI-FECG remains difficult and largely unexplored. This is mainly due to the relatively low signal-to-noise ratio of the FECG compared to the maternal ECG, which overlaps in both time and frequency.

The problem therefore consists in finding one or more data representation spaces well suited to the problem of fetal ECG extraction. It will be a question of applying and testing one or more methods starting from an article which reviews recent advances in research on NI-FECG, in particular: databases accessible to the public, techniques of NI-FECG extraction for fetal heart rate assessment and morphology analysis, NI-FECG simulators, and methodology and statistics to assess the performance of extraction algorithms.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Probability 1A (CIP-EDP, 1SL1000),
Signal processing ST4 (1CC4000)
Statistics, Machine learning and Data processing ST4 (1CC5000),
Digital environment, computer and programming SG1 (1CC1000).

Syllabus

Evaluation and implementation of non-invasive fetal ECG extraction algorithms, based on the article by Joachim Behar et al. “A practical guide to non-invasive fetal electrocardiogram extraction and analysis”, Physiol. Meas. 37, 2016.

Class components (lecture, labs, etc.)

This teaching is done in the form of a project.

Throughout the duration of the project, students will be asked to keep an up-to-date "laboratory notebook" specifying in a few lines for each experiment or test carried out, its motivations, the results obtained, the source codes and the data used. During the last week dedicated to the project, students will be asked to:

- provide a project report; and
- to carry out a defense in the presence of the partner.

A progress update on the project with reading of the "laboratory notebook" and the provisional version of the report will take place regularly.

Grading

Skills will be assessed:

- in continuous control at the advancement points, the "laboratory notebook" reading and the draft report reading (individual note CC);
- during the final defense (individual note S).

In addition, the quality of the deliverables: final report, "laboratory notebook" and commented source codes, will be evaluated (note QL).
Final score = CC/3 + S/2 + QL/6.

In case of a justified absence to one of the intermediary examinations, the grade of this latter is replaced by the grade of the final defense.

The assessment of skills is specified in the paragraph "Description of acquired skills"

Course support, bibliography

Joachim Behar, Fernando Andreotti, Sebastian Zaunseder, Julien Oster and Gari D Clifford, “A practical guide to non-invasive fœtal electrocardiogram extraction and analysis”, Physiological Measurement, 37, R1 – R35, 2016.

Resources

80 HEE (48 HEE) of project carried out in groups of students.

Learning outcomes covered on the course

At the end of this course, students will be able to:

- represent and decompose electrocardiograms in an "optimal" way;
- fit a model to data;
- use a programming language to effectively implement a data processing algorithm.

Description of the skills acquired at the end of the course

C4 : Have a sense of value creation for his company and his customers (assessed during project monitoring)
C6 : Be operational, responsible, and innovative in the digital world (assessed throughout the project)
C7 : Know how to convince (evaluated during the follow-up, during the defense and in the deliverables)
C8 : Lead a project, a team (evaluated by laboratory notebooks)

ST7 - 81 - ADDITIVE MANUFACTURING DESIGN

Dominante: CVT (Construction, City and Transportation)

Langue d'enseignement : English

Campus : Paris-Saclay

Engineering problem

Since its inception, additive manufacturing has proven to be a fundamental change in manufacturing processes, allowing total customization and artisanal quality at the cost and precision of a modern industrialized process. However, it is a young process, and therefore, not yet fully mastered. The mechanical properties of the parts produced are often unpredictable, severely limiting their use in high-end applications. This is why the development of methods (analytical and numerical) capable of predicting the final characteristics of the part by optimizing the design process seems a necessity.

The sequence focuses on the optimization of the design by additive manufacturing:

- Optimal choice of material and microstructure;

- Optimization of geometry with respect to multiphysical constraints;

- Optimization of process parameters (printing path, laser power, powder characteristics...)

- Evaluation of the economic and social stakes of FA compared to standard processes (manufacturing time, cost of materials, labor employed, environmental compatibility...)

This design presents a major challenge due to the multiphysical nature of the additive manufacturing process (thermal, mechanical, electromagnetic, metallurgical, phase change) and poses a multiscale problem both in space and in time (evolutionary nature of the process).

Adviced prerequisites

It is advisable to have taken the SPI course "Mechanics of Continuous Media" and at least one of the following courses: Materials, Transfer Science, Thermodynamics.

Context and issue modules:

These modules include lectures, a study-case and a mini-project, aimed at presenting the problem, the social and economic stakes and making a simple object using 3D printing.

Specific course (60 HEE): Multiphysics coupling

Brief Description:

This course will address the concepts and issues of multiphysics coupling in a broad sense. The following topics, among others, will be covered during the course:

- Strong - weak coupling
- Coupling of different formulations
- Coupling of different scales

Then we will focus on particular couplings, of interest for additive manufacturing:

- Laser on powder: electro-thermal coupling
-Powder bed melting: discrete-continuous, solid-fluid and thermo-mechanical coupling
- Cooling phase: aerothermal-mechanical coupling

The course will end with a reflection on the mechanics of the final part (residual stress, porosity, microstructure...).

A strong emphasis is placed on practice through tutorials and a case study on the multiphysics simulation software COMSOL. The acquired skills are evaluated by the case study.

Projects:

Brief description:

The sequence is built around various projects carried out by the CVT major. The students, in groups of 6 maximum, will have to answer a problem proposed by their industrial partner around the design of a part in additive manufacturing. This may involve optimizing its geometry, thinking about its design, designing a system for a given use, analyzing the performance of the part designed by additive manufacturing, etc. Most of the topics involve finite element simulation on COMSOL or on the software of the students' choice. Some topics may involve experimental work.

All projects should follow the following steps:
- Step 1: Getting to know the subject
- Step 2: Simplified representation of the problem to arrive at a first solution
- Step 3: Optimization of the system in a given parameter space
- Step 4: Analysis of the cost-benefit of the proposed solution compared to an initial or classical solution.

Examples of partners and associated themes: Safran for aeronautical parts in metal additive manufacturing, ESA for the design of structures for space applications, XtreeE for the optimization of civil engineering structures in gypsum or concrete additive manufacturing, Michelin for the production of optimized treads in polymer additive manufacturing, as well as research topics with the LMPS and LURPA laboratories.

2SC8110 – Multiphysical couplings for additive manufacturing

Instructors : **Camille Gandiolle, Andrea Barbarulo**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Specific course**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

This course will cover in a broad sense the concepts and challenges of multiphysical coupling.

Quarter number

ST7

Prerequisites (in terms of CS courses)

To have completed the "continuum mechanic" SPI course and at least one of the following courses: Materials, Transport phenomena, Thermodynamics.

Syllabus

This course will cover in a broad sense the concepts and challenges of multiphysical coupling.
The following topics will be adressed:

- Strong - weak coupling;
- Coupling of different formulations;
- Coupling of different scales.

Then particular coupling, of interest for additive manufacturing will be studied in more details:

1. Laser on powder: electro-thermal coupling
2. Powder bed melting: discrete-continuous coupling, solid-fluid coupling and thermo-mechanical coupling
3. Cooling phase: aerothermal-mechanical coupling

The course will end with a reflection on the mechanical behavior of the final part (influence of residual stress, porosity, microstructure...)

Class components (lecture, labs, etc.)

- 1 refresher course in MMC and a COMSOL tutorial to complete independently. Self-evaluation MCQ available
- 6 x 1.5 hr lectures and 7 x 1.5 hr tutorials
- 2x3h supervised case studies.

Grading

The knowledge will be tested by a MCQ (multiple-choice questionnaire) (=N1) and the skills acquired will be tested by a case study in groups of 3 consisting in implementing a coupled system by finite element modeling on comsol (N2=80%group result + 20%individual note).
The MCQ (N1) counts for 80% of the final mark; the N2 mark counts for 70% of the final mark.

Course support, bibliography

- Zhang, Qun, and Song Cen, eds. "Multiphysics Modeling: Numerical Methods and Engineering Applications". Tsinghua University Press Computational Mechanics Series. Elsevier, 2015. https://univ-scholarvox-com.ezproxy.universite-paris-saclay.fr/catalog/book/docid/88831751?searchterm=multiphysics
- Peksen, Murat. "Multiphysics Modeling: Materials, Components, and Systems". Academic Press, 2018

Resources

The following digital tools will be used to support the course: COMSOL

Learning outcomes covered on the course

- Master the different types of coupling;
- Know how to choose a modeling strategy in a multiphysics system;
- Know how to formulate a model integrating a coupling.
- Know how to simulate this coupling in COMSOL and use the software in a relevant way to draw conclusions on how to optimize the system

Description of the skills acquired at the end of the course

- C2 Develop in-depth skills in an engineering field and a family of professions
- C6 Be operational, responsible, and innovative in the digital world

2SC8190 – Structure optimization in additive manufacturing

Instructors : **Camille Gandiolle**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Project ST7**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

Optimization of the phsical properties (mechanical, acoustic, thermacl, etc.) of a part proposed by an industrial or academic partener. The optimized design must take into account the constraints of the additive manufacturing process.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Completion of the SPI "Continuum Mechanics" course and at least one of the following courses: Materials, Transfer Science, Thermodynamics.

Syllabus

The sequence is built around various projects supported by the CVT major. Students, in groups of no more than 6, will be asked to respond to a problem proposed by their industrial partner concerning the design of an additive manufacturing part. This may involve optimizing the geometry, thinking about the design, designing a system for a given use, or analyzing the performance of the part designed by additive manufacturing. Possible fields of application include aeronautics, biomedical, civil engineering, space... Most topics involve finite element simulation on COMSOL or on the software of the students' choice. Some topics may involve experimental work.
All projects must follow the following steps:
- Stage 1: Getting to grips with the subject
- Stage 2: Simplified representation of the part studied to arrive at a first solution
- Stage 3: Optimization of the system within a given parameter space
- Stage 4: Cost-benefit analysis of the proposed solution compared with an initial or conventional solution.

Class components (lecture, labs, etc.)

Students will have the opportunity to carry out an initial simple mechanical optimization, and to discover data processing for additive manufacturing through a collaborative activity with La Farbique. The part will then be printed and tested. Validating this activity enables you to validate Competency C6.

Grading

Skills C2 and C8 will be assessed throughout the project, which will culminate in an oral presentation in the presence of the industrial partner. Competencies C2 and C7 will be assessed during the oral presentation. The partner will assess skill C4.

Continuous assessment during the project (C2, C8) : N1
Teachers' grade for oral presentation (C2, C7) : N2
Industrial partner grade (C2, C4, C7) : N3
C6: PASS or FAIL validation with La Fabrique activity

NF = 30%N1 +30%N2 + 40%N3

Resources

School software, in particular COMSOL
LMPS experimental facilities

Description of the skills acquired at the end of the course

- C2 Develop in-depth expertise in an engineering field and a family of professions
- C4 Create value for company and customers
- C6.2 Practice collaborative design using product design and prototyping tools (CAD, 3D printer) ;
- C7 Convincing ;
- C8 Manage projects and teams

ST7 - 82 - PHYSICAL NEURO-INSPIRATORY SYSTEMS FOR INFORMATION PROCESSING

Dominante**:** PNT (Physics and NanoTechnology)

Langue d'enseignement **:** English

Campus **: Metz**

Engineering problem

In a context of constant increase of the volume of information to be processed, it is necessary to define new analysis strategies. Automatic classification methods based on machine learning are promising, but their numerical implementations remain slow and very energy-consuming. An alternative solution consists in designing hardware architectures called neuro-inspired, which allow to lift a large part of these barriers. This theme is attracting growing interest both in fundamental research and among start-ups and large high-tech groups such as IBM and Google.

In this context, and through a specific architecture known as the reservoir computer (an artificial neural network for which only a final reading layer is trained), we propose to students to discover the design principles of physical neural networks. For this, students will use many optimization techniques such as ridge regression and gradient descent, as well as their accelerated versions, or stochastic heuristics (e.g. simulated annealing, genetic algorithms).

The objective will be to simulate and test a prototype of a physical neuro-inspired processing architecture comprising several tens, even hundreds of thousands of neurons and to demonstrate its low energy consumption, to determine the equivalent number of floating operations per second achievable compared to a computer on classification tasks.

Adviced prerequisites

Knowledge of equations and dynamical systems. Courses in statistics, signal processing and automation, good command of a programming language (e.g. Matlab, Python, or C/C++).

Context and issue modules: These modules include an introductory conference on the theme by personalities from the academic and industrial worlds, presentations on the technological and scientific obstacles, and a presentation of the associated projects.

Specific course (60 HEE) : Optimization for learning physical systems

Short description:

This course presents the physical and mathematical tools for the realization and training of artificial neural networks: echo state network (ESN), electronic and photonic implementations, memory and computational capacity of physical architectures, supervised and unsupervised learning, ridge regression and regularization, accelerated gradient descent techniques, heuristic methods, hardware approaches for deep networks, emerging technologies (e.g. integrated photonics, nano-photonics and spintronics)

Project: High performance and low energy cost classification of video signals and images by photonic systems

Associated partners: Start-up Light On, CentraleSupélec / Photonics Chair and FEMTO-ST Institute

Location: Metz campus

Short description :

The project will focus on the learning/optimization of an experimental photonic architecture of a neuro-inspired analog computer (developed in CentraleSupélec laboratories in collaboration with the FEMTO-ST Institute). Students will have to choose learning/optimization strategies from the course and implement them so that the photonic architecture can perform image/video signal classification or solve industrially oriented problems proposed by our industrial partner Light-On. The organization of the project is as follows:

1) Rapid bibliographical study of the image or video signal classification task (or task proposed by the Light-On partner)

2) Numerical simulation on a realistic model of the architecture (provided) under Matlab. Implementation of learning methods based on linear/ridge regression, multi-logistic regression, or stochastic heuristics (unknown cost function model).

3) Identification of important physical hyper-parameters (experimentally adjustable) for the photonic architecture

4) Experimental tests, performance analysis, evaluation of the computational capacity (flops) and comparative study of the energy performance (energy cost per processed image/video sequence) compared to software methods.

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2SC8210 – Optimization for neuro-inspired computing with physical architectures

Instructors : **Damien Rontani**
Department : **CAMPUS DE METZ**
Language of instruction : **ENGLISH**
Type of course : **Specific course**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

The ever-increasing amount of data generated requires the development of novel processing/analyzing strategies. Automatic classification techniques originating from the field of Machine Learning are a promising candidate, however, their digital implementations remain relatively low and energy-intensive. An alternate solution consists of designing physical (hardware) neuro-inspired architecture that allows the alleviation of parts if not all of these technological challenges. This theme is the current focus of research laboratories worldwide and has caught the attention of large technological groups such as IBM or Google.

In this particular context and through the framework of *reservoir computing*, which consists of an artificial neural network trained only at its final output layer, This module proposes to the students to discover the principle of conception and design physical (hardware) neuronal networks. Toward this, the students will be familiarized with various optimization techniques such as ridge regression or gradient descent and their accelerated versions, or stochastic heuristics (ex. simulated annealing, genetic algorithms...).

Quarter number

ST7

Prerequisites (in terms of CS courses)

Basics of General Physics (Ordinary differential equations and partial derivative equations) (level L2)
Modeling (1CC3000)
Statistics and Machine Learning (1CC5000).
Digital Signal Processing (1CC4000)
Computing and programming skills in Matlab, Python, or C/C++.

Syllabus

Physical neuro-inspired architecture (6h L + 6h SC)

- Introduction to artificial neural networks (perceptron, feed-forward and reccurent networks)
- Physical implémentations in electronics, photonics and spintronics
- Review of essential notions in dynamical systems. Introduction to nonlinear systems.
- Notions on echo-state networks (ESN) and liquid state machines (LSM) – Reservoir computer and necessary conditions for information processing
- Memory Capacity (MC) and Computational Ability (CA)
- Integrated and nanoscopic physical systems for machine learning
- Perspective on deep physical architectures (deep neural networks)

Small Class / Labs #1 : Numerical simulation of an ESN for solving a regression task (3h)
Small Class / Labs #2 : Numerical simulation of a reservoir computer for solving a classification task (3h)

Machine Learning and Optimization for physical neuro-inspired architectures (15h L + 1.5h SC)

1. Basics in Machine-Learning and connection with optimization
2. Supervised and unsupervised learning, loss function, learning curves, cross-validation
3. Offline supervised learning (batch): linear (Moore-Penrose) and ridge regression - Online Learning : gradient descent (stochastics, mini-batch, averaged), recursive least square method.
4. Acceleration of first order methods.
5. Solving classficiation tasks (winner-takes-all, multi-logistic regression)
6. Machine Learning and parametric optimisation for physical architecture (reservoir computing architectures).

Small Class #3 : Implementation of online optimization techniques (1.5h)

Class components (lecture, labs, etc.)

Lectures with emphasized interactions with numerical and experimental demonstration in the lab. The presentation of mathematical tools is limited to essential notions necessary for the understanding of concepts seen in class.

Two Small classes will be organized for the assimilation of key notions

Hourly volume:
Lectures + interactive demonstrations : 21h
Small class: 7.5h
Final Exam: 1.5h

Grading

Final Exam : Duration : 1.5h - 50% of the final grade

- In case of unjustified absence, the grade is 0 for this part of the grade

- Homework (similar to.a mini project)with numerical simulation to solve a particular task or Analysis of a scientific article with a short report (5 pages max) - 50% of the final grade
    - If the report is not sent prior to the deadline, the grade is 0 for this part of the grade.
- Second Session Exam : In case of failure at the final exam, an oral exam of 20 min will be scheduled.

Course support, bibliography

D. Brunner, M. C. Soriano and G. Van der Sande, "Photonic Reservoir Computing: Optical Recurrent Neural Networks" Ed. De Gruyter (2019)

Resources

Teaching Staff / Faculty : Damien Rontani & Piotr Antonik
Computing ressources for numerical simulation and remote access to an experimental setup located in CentraleSupélec Laboratories

Learning outcomes covered on the course

This specific lecture will be divided in three sections with the following learning objectives :

- Simulate and experiment with physical implementation of artificial neural networks
- Apply various optimization techniques as learning strategies and apply them in the specific context of physical architectures

- Synthetize/summarize recent advances and state-of-the-art results on the implemenation of neuro-inspired physical systems on electronic/photonic chips for application in ultrafast information processing

Description of the skills acquired at the end of the course

C2 Develop in-depth skills in an engineering field and a family of professions
C6 Be operational, responsible, and innovative in the digital world

2SC8290 – Classification of image and videos signals with power-efficient photonic systems

Instructors : **Damien Rontani**
Department : **DOMINANTE - PHYSIQUE ET NANOTECHNOLOGIES**
Language of instruction :
Type of course : **Project ST7**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

This project is part of the thematic sequence ST7 "Physical Neuro-inspired Systems" and is about the automatic classification of image / video signals using photonic architectures developed within The CentraleSupelec Research Center. There are many applications to classification of images or video sequences such as assistance of diagnosis in healthcare, autonomous robotics, or scene analysis for defence and security.

Various software-based techniques exist to solve classifcation tasks and they run on central processing units (CPU) or graphical processing units (GPU). The downside is usually reduced processing speed and high power consumption during learning and testing phase. These are strong motivations for the development of alternative hardware (physical)-based architectures using analog electronics or photonics.

The objective of this project will be : (i) the study of the ability of a photonic architecture to classify video or images from publicly available databases, (ii) the optimization of its performance to be competitive with state-of-the-art software solutions and (iii) provide an estimation of the power efficiency of the architecture.

Quarter number

ST7

Prerequisites (in terms of CS courses)

Modeling (1CC3000)
Digital Signal Processing (1CC4000)
Statistics and Machine Learning (1CC5000)

Syllabus

1. Numerical simulation of a large-scale neuro-inspired photonic architecture (>10,000 interconnected dynamical systems)

- Choice of software language : *e.g.* Matlab / Python or C/C++
- Use of different learning strategies : (i) offline (*e.g.* linear and ridge regression, stochastic heuristics) or (ii) online (e.g. gradient descent and their accelerated versions).
- Search of optimal operating points with parametric exploration

2. Handling of a publicaly available database of video or image signals

1. Choice and analysis of pre-processing algorithm for "features" extraction suitable for classification tasks.
2. Techniques for the dimensionality reduction of the "features"

3. Experiment on prototype architecture

- Implementation of the chosen learning technique on the physical setup. (experimental settings and tuning done by the teaching staff)

- Experimental campaign

4. Performance analysis

- Performance (error / success rate in classification) and comparison with the state of the art (bibliographic search)
- Estimation of the power consumption for the resolution of a task (including the energy consumption during the training and energy use per signal processed)

Class components (lecture, labs, etc.)

This class is a small project with the following requirements :

- team-work (3 à 4 students) for 80 HEE (*i.e.* 41.5 HPE).
- organization of periodic meeting with teaching staff to monitor overall progress on the project, the code development, and for discussing the numerical and experimental results obtained.
- Writing one mid-term report (approx. 5 pages) on overall progress and including some technical details and a final report (approx. 10 to 15 pages) for the last week of the class.
- Two oral defenses : one mid-term defense (S1) only with the teaching staff and a final defense (S2) at the end of the project with the participation of industrial and academic partners.

Grading

The evaluation process is as follows :

- Continuing evaluation (CC) on project management (including but not limited to regular scheduling of meetings, progress, technical mastery of the topic...). Group and invidual performance will be taken into account and weighted equally.
- Two oral defenses (S1 et S2) Group and invidual performance will be taken into account and weighted equally.
- Technical content and quality of written material (L) (reports, bibliographic archives, commented source codes...).

Final grade = CC / 3 + (S1+S2)/6 + L/3

Resources

- Teaching staff : Damien Rontani, Piotr Antonik
- Desktop computers from the LMOPS laboratory of Metz Campus and the FUSION Super Compyter (Paris-Saclay) available for intensitve numerical simulations and parametric analysis.
- Personal computer of students
- Remote access to an experimental setup for testing on a prototype architecture developed within the LMOPS laboratory on Metz Campus

Learning outcomes covered on the course

By the end of the this project, the students will be able to

- Numerically simulate a large-scale dynamical system with Matlab / Python or C/C++ and apply offline and online learning techniques for the learning of physical architectures
- Analyze operating points and parametric mapping of performance of physical systems
- Use and apply pre-processing to publicly available database of image / video signals
- Experiment on prototype of photonic neuro-inspired architectures

Description of the skills acquired at the end of the course

C4 Have a sense of value creation for one's company and one's client
C7 know how to convince
C8 Lead a project, a team

INFOSEC CURRICULUM

2SC3000 – Compilation - Infosec

Instructors : **Pierre Wilke**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Specific Course**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

This course aims at providing students with a better understanding of the mechanisms used in compilers.

This is a fundamental topic because compilers are ubiquitous in the digital world. They are of course used to produce all executable programs, be it for PCs, smartphones, or even embedded systems.Even the design of processors is the result of the compilation of a high-level description into a logical circuit implementing the processor. More generally, every transformation process from an artefact expressed in a language, and producing another artefact in another language, often lower-level, can benefit from results obtained through 50 years of research in compilers.

We will study the different phases of a compiler : lexical, syntactic and semantic analyses, code generation, optimisations and associated program analyses, together with common executable formats.
This knowledge will be put in practice during the lab sessions, during which students will build a compiler for a small subset of the C language, targeting RISC-V assembly. The compiler will be written in the OCaml functional language.
The first lectures of this course will be dedicated to learning the C language (which we wish to compile) and the OCaml language (in which the compiler will be written).

Prerequisites (in terms of CS courses)

- Computer architecture (2A, SG6)
- Algorithms and Complexity (1A)

Syllabus

1. The C language
2. The OCaml language
3. Lexical analysis
4. Syntactic analysis
5. Code generation and program optimisations
6. Register allocation
7. Linking and assembly, executable file formats

Class components (lecture, labs, etc.)

8 lectures (3h)
9 lab sessions (3h)
1 TD (3h)

Grading

Written exam 1h30
Each core skill will be assessed by a part of the written exam.

Course support, bibliography

- Modern Compiler Implementation in Java. Andrew W. Appel, Cambridge University Press, 2nd Edition.
- Compilers: Principles, Techniques, and Tools 2nd Edition. Alfred V. Aho, Monica S. Lam, Ravi Sethi, Jeffrey D. Ullman
- Crafting Interpreters, Bob Nystrom
- Engineering a compiler, K. Cooper and L. Torczon

Resources

- Teachers : Frédéric Tronel and Pierre Wilke
- Equipment: a computer with the Linux operating system
- Software: opam, a cross-compilation chain for RISC-V, qemu-riscv64, docker (An installation guide will be provided at the beginning of the course)

Learning outcomes covered on the course

At the end of this course, the student will be able to:
- implement a lexical analyser
- implement a syntactic analyser for a LL(1) grammar
- design and implement, with fixpoint computations, static program analyses for optimisation
- implement a register allocation algorithm
- understand the structure of the stack during program execution.

Description of the skills acquired at the end of the course

3. C1.3
4. C2.1

2SC3090 – Project Compilation - Infosc

Instructors : **Pierre Wilke**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Project ST7**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **80**
On-site hours (HPE) : **40,50**

Description

This projet aims at improving the compiler obtained at the end of the lab sessions in the Compilation course (2PC3000)
The source language will be fleshed out, towards a language very close to the C language.
The compiler will be able to produce an executable for a small graphical game (Space Invaders).

Prerequisites (in terms of CS courses)

Compilation

Syllabus

Students improve their compiler along the following axes:
- function calls
- typing
- pointers
- arrays
- structs

Class components (lecture, labs, etc.)

12 lab sessions (3h each)

Grading

Oral presentation
Project code

Resources

- Teachers : Frédéric Tronel and Pierre Wilke
- Equipment: a computer with the Linux operating system
- Software: opam, a cross-compilation chain for RISC-V, qemu-riscv64, docker (An installation guide will be provided at the beginning of the course)

Learning outcomes covered on the course

Compile advanced constructs of the C language (function calls, pointers, arrays, structs)

Description of the skills acquired at the end of the course

C6.2
C7.1

INTENSIVE COURSES

2IN1510 – Understanding blockchain

Instructors : **Marc-Antoine Weisser**
Department : **INFORMATIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **24,00**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

The objective of this course is to understand the blockchain technology, to be able to explain it, to know in which context to use it and why it is not adapted in all contexts.

Quarter number

Intensive week SG6

Prerequisites (in terms of CS courses)

Good knowledge of the basics of Python 3.

Syllabus

The course is divided into 5 major parts.

I. Introduction to the blockchain and cryptographic elements
- The shared ledger
- Block chaining
- One-way function

II. Implementation of the blockchain
- Proof of work
- Nodes and miners
- Composition of a transaction
- Initialization of a chain
- Composition of a block
- Validation process

III. Advanced concepts
- Mining
- Crypto risk
- Other proofs
- Smart Contract
- Consensus
- Fork of the chain and resolution

IV. issues
- Pool and governance
- Vulnerabilities
- Ethics and legal

V. TP
- Implementation of a simple blockchain in Python

- Proposal of an application integrating it

Class components (lecture, labs, etc.)

- Lectures: 6x3h
- TP: 3x3h

Grading

Validation on the TP and a report.

Resources

- Lectures
- Practical Work
- Reading of support and synthesis

The courses and supervision of TP are provided by Marc-Antoine Weisser.

Learning outcomes covered on the course

At the end of this course, the student will be able to understand how works a shared ledger using blockchain technology, to know its possibilities, its issues and its limitations. The student will have acquired:
- basic elements of asymmetric cryptography (one-way function, hashing, public key and private key, etc.);
- the fundamental elements of blockchain technology (block chaining, proof of work, nodes, mining, composition of a block, etc.);
- some extensions and alternatives (proof of stake, smart contract, consensus, ...);

- the stakes (security, governance, vulnerability, ...).

Learning outcomes:
- Know the principles of asymmetric cryptography
- Understand how blockchains work
- Implement a blockchain
- Distinguish the relevant use cases of a blockchain
- Design an application implementing a blockchain

Description of the skills acquired at the end of the course

C1.1: Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem
C1.4 : Design, detail and corroborate a whole or part of a complex system.

2IN1520 – Risk analysis - INFOSEC

Instructors : **Valerie Viet Triem Tong**
Department : **CAMPUS DE RENNES**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Fundamental Sciences**
Advanced level : **No**

Description

This week of courses alternates between lectures and practical case studies to present cyber risk analysis.

A cyber security risk analysis is about understanding, managing, controlling and mitigating cyber risk across a digital organization.
Risk analysis a crucial part of data protection efforts.

Quarter number

semaine bloquée en fin de SG8

Prerequisites (in terms of CS courses)

none

Syllabus

Threat Analysis
who the attackers are, what are their motivation and organisation, their characteristics
Cyber Threat Intelligence
Study of some APTs

Risk analysis

- purpose of risk analysis
- presentation of different approaches
- focus on Ebios-RM

Technical security

Legal framework

Physical Security
Study of the modus operandi of attacks exploiting vulnerabilities in the implementation of physical security

Security in the Industrial sector

Crisis management
Practical study of three cases of cyber-attacks and the coordination of the response of internal and external actors in the management of the related crisis.

1. Crisis management process (Attack against TV5 Monde)
2. Crisis communication (Attack on Norsk Hydro)
3. Remediation (NotPetya attack against Maersk)

Social Engineering
Analysis of pressure tactics based on social engineering techniques

Class components (lecture, labs, etc.)

A week with some traditional classes and lots of interaction with lecturers through

Concrete situation on many small examples
Practical case studies in small groups and feedback to the whole group
Discussion with Philippe Thomazo, CEO of the ECOCERT group who will testify on his experience of cyber risks.

Grading

Evaluation of written knowledge with the help of a quiz and via oral restitution of the case studies made during the week.

Resources

Course materials, videos, testimonials, case studies

Learning outcomes covered on the course

Taking into account the Cyber risk
Assessing the real impact of a cyber-attack on the company's business
Understanding the threat organization
Consider the different aspects of cyber crisis management

Description of the skills acquired at the end of the course

C1 Analyse, design and implement complex systems made up of scientific, technological, social and economic dimensions.

2IN1570 – Web and mobile application development

Instructors : **Benoit VALIRON**
Department : **DÉPARTEMENT INFORMATIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Fundamental Sciences**
Advanced level : **Yes**

Description

Current web technologies go beyond than simple static webpages. Dedicated to interactions, they are versatile enough to be able to design application for all kind of terminals, from desktop to smartphones. Connected to the internet, these apps exchange data based on a common set of formats to structure and manipulate it, such as XML for example.

The objective of this course is to discover the technologies on which are based web-apps and mobile-apps, focusing on the use and manipulation of concepts and the realization of a small, yet complete application.

Quarter number

Intensive week at the end of the SG8

Prerequisites (in terms of CS courses)

The course "Information Systems and Programming" (ISP)

Syllabus

The course shall consists of the following 5 modules. 1 - Core concepts and technologies for the web ; 2 - Dynamic interaction with the user in the browser ; 3 - Structured data ; 4 - Architecture of a web-app and of a mobile-app.

Although registered students do not need to be expert programmers, it is however worthwhile insisting on the fact that the course will rely on **programming** (in javascript).

Class components (lecture, labs, etc.)

The course focuses on practicing the concepts: The presentation of a notion is followed with a lab-session to immediately apply and practice it.

Grading

The grading of the course is based on two things : 1 - continuous assessment, each lab session being submitted for evaluation, and 2 - each student will build and hand over a project implementing the concepts seen along the

course.

Course support, bibliography

The course consists in a series of tutorials, available online as the course will progress.
One can nonetheless cite the following bibliography:

- W. S. Means, E. Rusty Harold, XML in a Nutshell: A Desktop Quick Reference. O'Reilly, 2001.
- A. T. Holdener III, Ajax: The Definitive Guide. O'Reilly, 2008.
- B. Bibeault, Y. Katz, jQuery in Action. Manning, 2008.
- D. Flanagan, JavaScript: The Definitive Guide. O'Reilly, 2011.

Resources

The course is made of 5 modules incrementally presenting the core concepts of web and mobile programming. Each module consists in a theoretical part (with a corresponding lecture) and a practical part (lab sessions) for the students to manipulate the concepts.

Learning outcomes covered on the course

At the end of the course, the students will be able to

1. Know and use standards techniques of web-app design
    - Describe the various parts composing a web-app.
    - Implement each technology seen along the course to a simple case-study.

- Design and build a complete web-app, with client and server.
    - Propose a consistent orchestration of the components of the web-app
    - Allow different access mode to the service depending on the web-client
    - Evaluate and choose the pertinent technologies for a given goal

Description of the skills acquired at the end of the course

Skill C6.4 : Solve problems through mastery of computational thinking skills.

2IN1580 – Artificial intelligence and global health

Instructors : **Bich-Lien Doan, Marie-Anne Lefebvre**
Department : **DÉPARTEMENT INFORMATIQUE**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE RENNES, CAMPUS DE METZ, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Fundamental Sciences**
Advanced level : **No**

Description

The European University ALLIANCE FOR GLOBALHEALTH (Eugloh) is composed of nine universities (Saclay, Porto, Lund, Munich, Szeged, Hambourg, Novi Sad, Tromse, Alcala). They share the ambition of combining their expertise and resources in Global Health to offer the best education and training to their students. A pilot university, not only innovative, but also fully conscious of its responsibilities and ready to face societal challenges, in particular those related to Global Health. Training students as future leaders, both as experts in their fields and responsible citizens: curious, creative, and adaptable to diverse ecosystems and cultural environments.A collaboration framework open to contributions from all players and all fields concerned by Global Health.….

(see the brochure at https://www.eugloh.eu/about/vision-and-objectives/plaquette-EUGLOH-EN-page-par-page%20(1)%20(1).pdf)

This course is part of this alliance and offers students from five European universities an introduction to AI issues applied to health and well-being.

During the week, students will receive a course on artificial intelligence to understand more specialized interventions in the use of AI models in health and wellness applications.
The following courses will be given in the form of lectures or interactive workshops, face-to-face and distance, mixing students from 5 European universities. This course will therefore both acquire skills and knowledge in AI and health, but also an intercultural and international openness through exchanges between research professors and students of the Eugloh alliance
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Quarter number

Intensive week at the beginning of SG6

Prerequisites (in terms of CS courses)

No prerequisites except the level of English to follow the lectures in English.

Syllabus

o Introduction : Artificial Intelligence (AI) is the most powerful technology humans have ever had access to. AI will revolutionize all aspects of our lives, of which healthcare is not the least. But what exactly is AI ? We will see that this question is more complex than one might think at first glance. From image classification to knowledge processing to medical robotics, we will see on selected examples that AI is diverse and cannot (yet) be reduced to a one-fit-all technology. We will review the main AI techniques, what they rely on and their field of application. As the field is constantly growing, many questions are still open.
o Wellness workshop at home : No more TV couch where you receive formatted information. Replace it with a zone of action and interaction, to take care of yourself, your body and your mind, at home ! After discovering some examples of industrial or research concerts, we will invite you to imagine, in groups, tomorrow's solutions that will allow you to take care of your physical and mental health at home. What tools are needed ? What role can AI play ? How can information taken at home be returned to specialized services (sports coach, doctor, etc.) ? How acceptable can these solutions be for their users? Because well-being is not reserved for gyms or yoga studios and health is not only a matter for physiotherapists or hospitals, we will propose to imagine how this can be integrated in your homes. Chronic liver diseases are a major health problem in our modern societies. However, nowadays the reference procedure for diagnosis is based on biopsy, a potentially dangerous method that cannot be repeated regularly. In this course, we will see how "parsimonious decomposition" methods can be used to exploit "vibrational spectroscopy" data in order to develop new non-invasive and inexpensive automatic diagnostic methods.
o Lectures given by experts in the field of AI and global health. (Eugloh Speakers)
o Course on Ethical Issues. The Coronavirus pandemic has shaken our lives, reminding us of the fragility of existence, and bringing to the surface pressing ethical issues at individual, collective and international levels. Such issues include clinical ethics decisions regarding scarce healthcare resources allocation, the dilemma of protecting public health vs. suspending individual rights, and the research ethics question of testing vaccines without the usual precautions.

Class components (lecture, labs, etc.)

Interactive workshops, courses and conferences

Grading

Evaluation by a final test in the form of a quiz associated with the various interventions

Resources

Face-to-face/off-site at the Gif, Rennes or Metz campuses, off-site for teachers from other Eugloh universities

Description of the skills acquired at the end of the course

- C1.1 Study a problem as a whole, the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human dimensions
- C6.7 Exploit the possible connections between objects and people
- C9.1 Analyze and anticipate the possible consequences of one's choices and actions with respect to oneself, others and the environment
- C9.4 Demonstrate rigour and critical thinking in the approach to problems from all angles, scientific, human and economic

2IN1590 – Biomechanics and life materials

Instructors : **Elsa Vennat**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The link between mechanics and the living world is much closer than you might think. Did you know that our bone tissue evolves and adapts according to the mechanical load it is subjected to? This is important in our daily lives (regular moderate physical activity leads to better bone quality), but also in medical care (how do we replace or regenerate bone tissue after an accident?).
In this experimental elective, we'll be exploring the links between mechanics and the living world by observing and characterizing bone tissue. By their very nature, living materials are multi-scale. A comprehensive approach will be taken to characterize and model the chosen living material in three stages:

Bibliographical research (presentation of tools, then group research)

Observations at the various relevant scales: microscopic observation of samples, three-dimensional visualization of microstructure, image processing and analysis.

Experimental study of tissue behavior under loading, finite element modeling and critical analysis.

Quarter number

Intensive week at the end of SG8

Prerequisites (in terms of CS courses)

1EL5000 - Mécanique des milieux continus

Syllabus

Monday, all day
Choice of material to be studied
Presentation of bibliographical research tools and bibliographical research
A summary sheet will be handed in at the end of the session.

Tuesday, all day (in parallel) :
Observation of material microstructures (X-ray tomography, optical microscopy) + quantification (ImageJ software)
Preparation of specimens for mechanical testing
Preparation of samples for scanning electron microscopy

Wednesday, all day (in parallel):
Mechanical tests and analysis of results (global and local tests, compression and nano-indentation)
SEM observations (either on polished or fractured samples)
Final analysis of acquired images

Or
Finite element modeling in COMSOL
Creation of model geometry based on observations and local mechanical quantification
Analysis of mechanical behavior: critical comparison/analysis of numerical and experimental results
Late afternoon: Work on the progress review to be held on Thursday morning

Thursday
Morning: progress report: 5' presentation per group
Rest of the day:
Mechanical tests and analysis of results (global and local tests, compression and nano-indentation)
Finalization of image analysis
Or
Finite element modeling in COMSOL
Creation of model geometry based on observations and local mechanical quantification
Analysis of mechanical behavior: critical comparison/analysis of numerical and experimental results

Friday :
Morning: preparation of final presentation
Afternoon: final presentation

Class components (lecture, labs, etc.)

Practical work and tutorials

Grading

work / involvement in project group (15%) + bibliography (15%) + progress report (10%) + final presentation (60%)

Resources

Teachers : Elsa VENNAT, Shangaya TOURAIVANE, Margot LECLERCQ
Software tools: Comsol Multiphysics, ImageJ (or FIJI)

Learning outcomes covered on the course

At the end of this course, students will be able to :

- Search for reliable data in the bibliography,
- use microscopy tools adapted to the observation of hard biological tissue
- characterize porous biological tissue by image analysis using ImageJ
- Describe the behavior of biological tissues based on experimental curves (traction/compression),
- propose an experimental protocol for the mechanical characterization of hard biological tissue under simple loads
- Propose a simple geometric model and carry out a numerical study using the finite element method (COMSOL software) to evaluate the overall Young's modulus of this tissue.
- make the link between microstructure and mechanical properties for a hard biological tissue

2IN1600 – Design your way

Instructors : **Fabienne Berge**
Department : **DÉPARTEMENT DÉVELOPPEMENT PROFESSIONNEL ET MÉTIERS DE L'INGÉNIEUR**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Business Sciences**
Advanced level : **No**

Description

This course covers the fundamentals of self-knowledge (intellectual and relational functioning) and integrates the principles of Design Thinking in the construction of one's choices and career path. It is based in particular on the work of Stanford's Life Design Lab, which is well appreciated by students. It allows you to work on self-esteem, and to prepare for important choices to come. It also offers a framework for integrating different learning experiences at school (in class, API and APP workshops, Student organizations, sports highlights, etc.).
This course deals with the question of the freedom and responsibility of each individual in his or her school career, his or her choices of orientation, or the way to exercise his or her future profession as an engineer, based on guided introspection/reflection on concrete situations exposed (group discussions, videos, theoretical contributions). It leads to a greater awareness and capacity for individual questioning on the adequacy between one's actions and decisions, and one's own values. It gives students the opportunity to take a step back and think about their life view and work view.

It involves a significant individual commitment and work (readings, and Inter-Sessional Works).

Elective objectives: awareness of one's own individual functioning as well as that of others, for better autonomy and resilience in the face of choices and different stages of student and professional life. Awaken students to what influences their decision-making, as soon as they make their choices of curriculum and employment. Gain clarity, self confidence, and ability to inspire trust.

Quarter number

SG6 (in intensive week)

Prerequisites (in terms of CS courses)

none

Syllabus

1 - My past and present: Self-knowledge module with an Introduction that notes the difficulty of connecting with oneself (ref to Edgard Morin and Henri Bergson) in today's volatile, complex, uncertain world - Myers Briggs Type Indicator (MBTI) well recognized preference questionnaire that allows us to identify our inner preferences (in everyday life, with others, in our work environments) - Course on multiple intelligences : identify your resources among the 8 different forms of intelligence identified (cf Howard Gardner's model) in order to make the best use of them - Time to reflect on your values and motivational drivers to put at the heart of your life plan - time to integrate the different learning (courses, API, APP, student organizations, sports, company meetings, internship op...).

2 - My future: Use the Design Thinking tools and mindset to discover and develop the ability to generate new ideas when faced with a choice, and to adopt the right attitude at the end of a cycle (end of studies, end of a job or internship) in order to prepare to rebound towards the next cycle - Writing exercise (life view / work view) - Reflection work on 3 possible future scenarios (5-year period Odyssey plan).

Class components (lecture, labs, etc.)

Mix of theoritical and practical sessions. Mix of individual work and small group discussions. Training sessions to pitch on a project. Learning of graphic thinking tools/ visual dashboard design to work on possible scenarios - Video production - Book reading.

Grading

Presence - Involvement - Personal and team productions (essays + video) after each TD – book readings and presentations

Resources

- Teaching team (names of the teachers of the lectures): Fabienne Bergé - Catherine Chapuis
- Size of the TDs (default 35 students): 35 students maximum

Learning outcomes covered on the course

At the end of this course, the student will be able to : make better choices, introduce yourself to recruiters, be less dependent on others, be agile in a volatile and uncertain world where you need to know where you stand, better assess your priorities and acquire good reflexes to manage the breaks or rebounds to be made during your professional life, acquire a better ability to step back, develop your ability to generate ideas.
Skills Worked: C3, C7.2, C7.3, C9

Description of the skills acquired at the end of the course

C3 : Act, engage, innovate within a scientific and technological environment

C7.2 : Persuade through interpersonal relations to understand the needs and expectations of multiple participants in a dialogue, elicit reactions and create a climate of trust
C7.3 : Persuade by working on oneself; to be at ease within any environment, to work with both confidence and empathy, managing one's emotions and using communicative strategies.
C9 : Think and act as an accountable ethical professional

2IN2100 – Communicate on sustainable scientific Research

Instructors : **François CLUZEL, Bich-Lien Doan, Simon Meunier**
Department : **DÉPARTEMENT GÉNIE INDUSTRIEL ET OPÉRATIONS**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **24,00**
Elective category : **Fundamental Sciences**
Advanced level : **No**

Description

At the heart of the environmental crisis we are experiencing, transmitting and disseminating scientific and technical knowledge is a major expertise for engineers and researchers. This course is a life-size initiation to scientific mediation: in the space of one week, the objective is to appropriate, popularize, and format, via different media, a scientific and research discourse. By working on a real research project carried out by a researcher, the aim is to enhance its value by designing a tailor-made scientific mediation tool.
This course aims to introduce students to scientific mediation through an active pedagogy involving sustainable research projects, researchers, experts in the field and an audience in a real environment. It will be punctuated by lectures by accomplished popularizers.

Scientific mediation is a discipline that consists in establishing a link between the scientific world and society. It is as much about popularization and dissemination of scientific culture as it is about ethical or political dialogues. This discipline is therefore aimed as much at the general public who wish to satisfy their curiosity or make decisions as citizens, as at policy makers who must understand the scientific world and appropriate its knowledge. Engineers trained at CentraleSupélec, through the variety of their scientific skills and their familiarity with technical, economic and societal issues, are in a favorable position to participate in this mediation.

In this course, the topics addressed by the speakers and students will all be related to the Sustainable Development Goals, which represent a particularly important issue for scientific mediation in our time, and to which it is essential to raise the awareness of the general public and the political class.

Link to the flyer of the course (in French, copy and paste the weblink in a browser to ensure access to the doc):
https://drive.google.com/file/d/19mqtBO5U_Bwd0wt9vVpsBsIw9BZGk9jE/view?usp=sharing

Quarter number

semaine bloquée de SG6

Prerequisites (in terms of CS courses)

A strong motivation! This week requires a significant commitment to produce a mediation medium that is equal to the quality of the speakers and experts solicited.

Syllabus

o Introduction to the course, its objectives and organization
o Presentation of the Sustainable Development Goals (SDGs) set out by the UN in its Agenda 2030, contextualization, need for mediation and the main tools of scientific popularization
o Lectures and discussions led by great witnesses, mediators or accomplished popularizers: discover the

environment of scientific mediation, its habits and methods, learn the basics of mediation and the advice of experts, discover the behind-the-scenes of major projects
o Scientific popularization project on a target medium: students meet with CentraleSupélec researchers and take ownership of their research project, then choose a type of media to present this work to a non-specialist audience or to the general public. In addition to the researchers, the students are accompanied by the course supervisors and by experts in popularization or mediation, specialists in the media they have chosen.

Organization of the course:
The elective is coordinated by a team of supervisors in order to ensure coherence from the introductory course to the project defense.
- Monday :
o Morning: Introduction and presentation of the week's issues, mediation tools
o Afternoon: Project exchange, meeting between researchers and students, led by the supervisors of the elective. Choice of topics and media
- Tuesday:
o Beginning of the work in project mode, with coaching by the supervisors and intervention of a media expert
o CHALLENGE: My Project in 180 seconds
- Wednesday :
o Morning: Conference and discussion with great witnesses
o Afternoon: Project mode work coached by the supervisors and intervention of an expert
- Thursday :
Morning: Work in project mode coached by the supervisors and intervention of an expert.
- Friday :
- Morning: Finalization of the project

- Afternoon: Project presentation and defense (pitch session with a jury of experts + forum to present the results to a large audience)

Great witnesses examples of past years:
- Sylvestre Huet, scientific journalist (Le Monde)
- Aurélien Déragne, creator of Fresque du Numérique
- Anatole Chouard, youtuber et scientific popularizer
- Célia Quilleret, scientific journalist (France Inter)

Media experts examples of past years :
- Célia Quilleret, scientific journalist (France Inter)
- Laure Andrivot, designer, expert of design applied to environmental issues
- Hugo Cayla, engineer and PhD, video maker, member of 7pointsproduction

Examples of past projects (copy and paste the weblink in a browser to ensure access to the doc):
- 2021: https://www.centralesupelec.fr/fr/ingenieurs-vulgarisateurs-de-science
- 2022: https://www.linkedin.com/posts/projet-celsius_retour-sur-la-semaine-exceptionnelle-que-activity-7008022036262330368-3iuJ?utm_source=share&utm_medium=member_desktop

Class components (lecture, labs, etc.)

- Conference and discussion with a great witnesses
- Work in project mode, with coaching by the supervisors and the intervention of a media expert
- CHALLENGE: My Project in 180 seconds

Grading

Evaluation on the quality of the project, as well as the quality of the end-of-week presentation. Evaluation by peers and by the supervisory team.

Resources

- Slides of the supervisors and experts
- Physical, audiovisuel and digital prototyping means
- Course supervisors: Bich-Liên Doan, François Cluzel and Simon Meunier
- Teaching staff: François Cluzel, Bich-Liên Doan, Simon Meunier, Projet Celsius (https://www.projetcelsius.com/), popularization and sustainable development experts
- Groups size: groups of 3 students

Learning outcomes covered on the course

- Create a simple outreach material for a specific audience
- Carry out a popularization project, from the research of ideas to the presentation of the material
- Know the stakes of scientific communication, in the context of sustainable development
- Evaluate the quality of a popularized information, and know how to correct or improve it if necessary
- Describe the different environments favourable to scientific communication, their advantages and their habits

- Use research to transmit their knowledge to a non-initiated public
- Choose an adequate communication support according to the topic and the target audience

Description of the skills acquired at the end of the course

- C1.1 Study a problem and the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human dimensions
- C3.5 Propose new solutions/tools either in rupture or in continuous progress
- C6.7 Exploit the possible connections between objects and people
- C7.1 Convince on the substance. Be clear about the objectives and expected results. Be rigorous about the hypotheses and the approach. Structure his/her ideas and arguments. Highlight the value created
- C7.4 Master spoken, written and body language. Master basic communication techniques
- C9.2 Perceive the field of responsibility of the structures to which one contributes, by integrating the environmental, social and ethical dimensions
- C9.4 Demonstrate rigor and critical thinking in the approach of problems from all angles, scientific, human and economic

2IN2180 – Procurement management

Instructors : **Thierry Reboud**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Business Sciences**
Advanced level : **No**

Description

This program intends to provide students with basic knowledge and skills to master the main purchasing processes in which they will be involved, regardless of the functions they will perform in a company.

As future top managers, students will be able to evaluate the full benefit they can expect from the purchasing function, and to identify the main drivers to monitor and leverage the relations with suppliers (organisation,, purchasing policy, performance assessment, targets...)
The course and case studies are in English, the world language of global purchasing

Quarter number

Intensive week at the end of the SG8

Prerequisites (in terms of CS courses)

No prerequisite

Syllabus

The program is split into several modules
1 – What is Purchasing? Target is to introduce the basic concepts (Vocabulary clarification, purpose of purchasing, Scope of activity...)
2 – Purchasing policy - Marketing approach. Target is to explain the concept of “purchasing strategy” (why?, What?, How?)
3 – Pricing. Target is to fully understand the fundamnetal gap between "cost" and "selling price"
4 – RFQ – Supplier selection. Target is to understand the 4 steps of the selection process, how to choose the relevant criteria to evaluate quotations, and how to organize the selection
5 – Make or Buy. Target is to understand the various aspects to be considered for a Make or Buy decision, and how to process it
6 – Legal. Target is to provide the legal background requested in the purchasing activity, and identify the main legal risks related to purchasing
7 - IP. Target is to highlight the importance of IP protection, and explain how to secure IP in the relations with suppliers
8 – Negotiation. Targets are :
  to understand why and how to prepare negotiations, identify the successful negotiation behaviours for a buyer,
  to provde background about some specific negotiation situations (conflicting, multicultural, negotiation team..)
  to give an overview on "auction" tools.
9 – Supplier assessment – Sustainability. Target is to identify the list of useful criteria, to understand how to perform such assessment, and to give some financial background to detect a the sustainability risks.
10 – Value creation – Performance. Target is to explain the purpose of the purchasing performance assessment, and how to implement it, what is “value” for a company, what are the KPI, how to choose them
11 – Ethic & Management : Targets are to identify the main successful skills and qualities for a purchasing

function, and to give an overview about the main ethical issues that may result from relations with suppliers.

Class components (lecture, labs, etc.)

Course material and case studies are circulated to students at least one day ahead of the course, to be studied and acquired , and to generate questions and discussions which are encouraged during course.

Through real life situations related to each course, students are given roles as purchasing manager, or other contact persons, to aim for objectives which are sometime complex and even contradictory.
During role-playing games, they will have to convince and fight for their assigned role, facing others with different purpose.

The case study for grade must be investigated in details to demonstrate an appropriate level of mastery. Simple course theory is not a sufficient answer.

Grading

The students grade is the result of 2 grades of identical 'weight':

The first one evaluates active participation to the course (presence in class and active interventions during the course or case reviews)
The second one results from a case analysis study outside class, individually of in teams.

Competencies acquisition:
C4 (value creation): Multiple choice questions in writing, outside class
C7 (know how to convince): under development

Resources

The sessions combine formal review of the subject matter, plus reviews of one or several case studies which have been distributed in advance for preparation by the students. The purpose of these studies is to understand how theory has to be sometime adapted to match 'real life situations'.

Learning outcomes covered on the course

On completion of the course, students should be able to:
- Identify and monitor the key purchasing processes
- Elaborate a purchasing policy consistent with the company strategy
- identify the main risks outcoming from relations with suppliers
- Assess suppliers and compare quotations, according to the most relevant criteria for the considered business.
- Prepare and perform negotiations
- Identify the created value that can be leveraged through the bargaining power

Description of the skills acquired at the end of the course

C4: sense of value creation for the company and its customers
C7: Know how to convince

2IN2310 – Individuals, Work, Organizations

Instructors : **Cynthia Colmellere**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **Common Course**
Campus : **CAMPUS DE METZ, CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

Starting with the basics of sociology, psychology, philosophy, politics, ethics, students will :
• Better know companies and the various working environments of engineers, specifically in relation to company organization and management,
• Understand the social and political and economic contexts of these various working environments,
• Understand the technical, scientific, social, human, economic and managerial dimensions of work and their relations,
• Understand individual and collective behavior at work,
• Understand the relations and the mechanisms of power in situations of cooperation, negotiation, conflicts,
• Understand the phenomena of abnormality and fraud,
• Understand failures and success of organizational change.

Quarter number

Intensive week of SG6 and SG8

Prerequisites (in terms of CS courses)

none

Syllabus

Examples of courses provided :
• Negotiation and management
• Conflicts and mediation
• Assuming responsibility in duty

Grading

Written essay to be delivered within ten days after the end of the course (at least 50% of the final mark)• Oral participation and presentations• Individual and team works. In case of a justified absence to one of the intermediary examinations, the grade of this latter is replaced by the grade of the final examination.

2IN2320 – Perspective on Key Social Issues

Instructors : **Cynthia Colmellere**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **ENGLISH, FRENCH**
Type of course : **Common Course**
Campus : **CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY, CAMPUS DE METZ**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

The main objective of this seminar is to help students orient their actions in the face of "major contemporary challenges".

To this end, the courses propose knowledge and methodologies of psychology, sociology, political science, economics, history, and anthropology to help students :

1. Understand and analyze issues related to contemporary environmental, human, and social problems. For example: global warming, energy challenges, social justice, participation of civil society.
2. Understand the effects of human practices on the natural, economic and social environment
3. Understand the ethical, political, social, and economic dimensions of the engineer's actions concerning these issues.

Quarter number

Intensive week of SG6 and SG8

Prerequisites (in terms of CS courses)

none

Syllabus

- Courses include:
- Business, Fraud, and Deviance: Managerial and Sociological Perspectives
- Exclusion/Inclusion in Contemporary Societies: The Social Science Perspective
- The media: socio-technical devices of social control?

Class components (lecture, labs, etc.)

The courses alternate theoretical contributions, case studies, and situational exercises.
The materials used are varied: texts (scientific articles), videos, podcasts.

Grading

Written essay to be delivered within ten days after the end of the course (at least 50% of the final mark)• Oral participation and presentations• Individual and team works.

Resources

The courses are given in classes of a maximum of thirty students by a teacher specialized in the proposed subject.

Description of the skills acquired at the end of the course

- Analytical skills: knowing how to identify the different components and actors of the situation, examining them in order to understand the relationships between them, bringing out non-obvious links.
- Ability to synthesize: synthesize the elements of a situation, identify the points of support and the difficulties.

2IN2330 – Science, Technology, Society

Instructors : **Cynthia Colmellere**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **FRENCH, ENGLISH**
Type of course : **Common Course**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES, CAMPUS DE METZ**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

These courses aim at helping future engineers understand the representations of science and technical progress to better their action and its effects. These courses are based on scientific studies, sociology of innovation, history of science and techniques, philosophy, ethics, and politics.
Students will be able to understand and analyze in various contexts and situations:
• The elaboration of the scientific and technical knowledge ·
• Distribution,
• Appropriation,
• Practices
• effects on individuals and society, specifically in terms of controversies

Quarter number

SG6 and SG8

Prerequisites (in terms of CS courses)

none

Syllabus

Examples of courses (in French and English) :

- Historical, Philosophical and Ethical Perspectives on AI and Data Science
- An introduction to the philosophy of science from the perspective of measurement
- Introduction to scientific and technical controversies

Grading

Written essay to be delivered within ten days after the end of the course (at least 50% of the final mark)• Oral participation and presentations• Individual and team works.

Resources

The courses are given in classes of a maximum of thirty students by a teacher specialized in the proposed subject.

Description of the skills acquired at the end of the course

-Contextualize the problems engineers will address as professionals to understand the different dimensions (technical, managerial, human, organizational, économical) and their direct connection with the dynamics of society

1. Identify the normative frameworks, world views, economic, ethical, and societal issues of the different actors concerned (employees, citizens, scientists, or institutions), and consequently their respective positions
2. Understand situations of innovation, uncertainty, controversy, crisis, economic and technological change, etc., to build the most appropriate solutions.
3. Knowing how to reconcile, articulate and integrate technical and scientific ("hard") knowledge and knowledge dealing with the human, social and cultural dimensions into their analyses, decisions, and actions.

2IN2340 – Innovation, Arts and Creativity

Instructors : **Cynthia Colmellere**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **ENGLISH, FRENCH**
Type of course : **Common Course**
Campus : **CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY, CAMPUS DE METZ**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

The main objective of theses courses is to adress the issue of innovation through artistic creation. Students will be able to:
• Understand the production of artistic works in various domains: architecture, painting, literature, design …
• Understand the relations between the various domains of the artistic creation ant science and techniques
• Understand the individual and collective dimensions of this work
• Understand the influence of the cultural, social, economic and political contexts in which they take place.
These courses are based on history, sociology, architecture, politics, philosophy

Quarter number

Intensive week of the SG6 and SG8

Prerequisites (in terms of CS courses)

none

Syllabus

Examples of courses (in french and in english) :
• Art, territoires, écologie
• Adressing Fiction : storytelling, literarity and fake news
• From cradle-to-grave : Tech won't save us

Class components (lecture, labs, etc.)

· The courses are given in classes of a maximum of thirty students by a teacher specialized in the proposed subject.

Grading

Written essay to be delivered within ten days after the end of the course (at least 50% of the final mark)• Oral participation and presentations• Individual and team works.

Description of the skills acquired at the end of the course

Analytical skills: knowing how to identify the different components and actors of a situation, a place, a creation/innovation environment, examining them to understand the relationships between them, revealing non-obvious links

2IN4000 – Business Games

Instructors : **Xavier Leon**
Department : **DÉPARTEMENT SCIENCES HUMAINES ET SOCIALES**
Language of instruction : **ENGLISH, FRENCH**
Type of course : **Common Course**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES, CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **30,00**

Description

The business games offer a practical, playful and synthetic approach to economics, management and psychosociology. They are an experience in collective decision-making, team interdependence and organization, conflict management, role taking and personal positioning in a group. The main objectives are:
- Discover the company and its main functions
- Introduction to management and accounting
- Experiment and become aware of the processes that develop in a teamwork (decision, organization, etc.)
- Analyse its contribution to the working group

Quarter number

Intensive week before the ST5

Prerequisites (in terms of CS courses)

Basic management knowledge and group work experience are useful

Syllabus

Business games are simulations of the lives of several companies competing in the same market. A game unit consists of 5 or 6 teams of 5 or 6 players each.
Each player has a particular responsibility: production, finance, human resources, marketing, general management. At the beginning, the situation of companies is identical. The task of each team is to analyse this initial situation and make decisions: sales, production, price, etc. objectives. The decisions of each team, aggregated and compared with each other, then shape a new market state where the situations of companies differ. The analysis of this new situation gives rise to new decisions and several cycles follow one another.

Class components (lecture, labs, etc.)

The games take place over 4 consecutive days, alternating simulation and debriefing sequences.

Grading

Three dimensions are taken into account in the evaluation of the games: - Acquired knowledge in economics and management and in the human and social sciences - Participation (leadership, involvement in the role) - The quality of the analyses during debriefings, both in terms of strategy/management and team lifebeyond a day of unjustified absence, students do not validate the business game

Resources

Teaching team (names of the teachers of the lectures): There are two types of teachers: the facilitators in charge of the game sessions and the specialists (SHS) in charge of the discussion and debriefing sessions

Learning outcomes covered on the course

- Understand the vocabulary of business management
- Understand the conditions of growth and difficulties of a company
- Understand the usefulness of summary accounting documents
- Understand the interdependence between strategy and operational decisions
- Understand the articulations of functions in a group
- Understanding human phenomena occurring in a group
- Identify your personal contribution in a team

Description of the skills acquired at the end of the course

Developing a professional posture relevant, reflexive and ethical (C9)

2IN5010 – Bridge Building challenge

Instructors : **Guillaume Puel**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH, FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The principle of this experimental teaching is to build, according to a given set of specifications, a cardboard bridge model capable of supporting the greatest possible load. The main objective is to highlight the interactions between modelling, experimentation and numerical simulation.

Quarter number

Intensive week of the SG6 and at the end of the SG8

Prerequisites (in terms of CS courses)

1EL5000 (Continuum mechanics) or 1EL4000 (Materials) or ST2 CVT (Modeling, simulations and experiments for the design of vehicles and structures) or ST4 CVT (Digital twins for efficient constructions and transportation vehicles)

Syllabus

- Monday, all day (in parallel):
  - Characterization of the mechanical properties of the cardboard
    - tensile tests on cardboard specimens cut in different directions to determine the moduli of elasticity, Poisson's ratio (using marker tracking) and tensile strengths (each group offers two different specimens and thus contributes to the realization of a collective experimental basis)
  - Brainstorming on the possible architectures for the bridge
    1. use of topological optimization software (TopOpt)
    2. study of first simple models with Comsol
- Tuesday, all day (in parallel):
  - Structural tests
    - compression tests on "profiled" beams
    - tensile tests on beams assembled by gluing
    - (possibly) tests of various assemblies
  - Design of bridge models
    - precise design of bridges using finer numerical models on Comsol and structural tests
- Wednesday, all day (in parallel):
  - Construction of bridge models (laser cutting of the designed parts at la Fabrique)
  - Complementary numerical models (or additional experimental tests)
  - Preparation of the next morning's presentations
- Thursday :
  - Morning: presentation of the different models
    - every group of students must announce the load that their model will be able to support
    - the groups also vote for the model they think will win
- Friday:
  - Morning: test of bridge models in a "challenge" configuration, analysis of test results and interpretation of discrepancies with predictions

- Out-of-classroom: writing of a summary note on the learning outcomes of the activity

Grading

work within the project + intermediate defense + final summary note.

Resources

- Software: Comsol (Structural Mechanics module)
- Equipment-specific classrooms: LMPS laboratory (Matter block of Eiffel building) to do the experimental tests

Learning outcomes covered on the course

At the end of this course, students will be able to:

- conduct tests for the mechanical characterization of a material or structure
    - experimentally determine the mechanical properties of a material for use in a real structure
    - conduct tests on real structures to evaluate their mechanical performance

1. dimension a structure from a mechanical point of view
    - propose models, analytical or numerical, and of increasing complexity, of real structures
    - obtain, using these models, relevant quantities to make design choices

    - present in a convincing and reasoned way a mechanical design approach
        - present the modeling choices and the results resulting from a mechanical dimensioning
        - explain the differences in performance of the real structure with respect to the developed model(s)

Description of the skills acquired at the end of the course

The validation of the milestones 2 of skills C1, C2 and C8 are assessed individually throughout the week, as well as in the Intermediate Defense and the Final Briefing Note from a team point of view.

2IN5015 – Contactless 3D scanning

Instructors : **Pascal MORENTON**
Department : **DÉPARTEMENT GÉNIE INDUSTRIEL ET OPÉRATIONS**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

Over the past twenty years, non-contact 3D scanning processes, in particular by laser triangulation, have been democratised and have become widespread in many sectors of activity in construction, industry and design. The objective of this activity is to get in touch with non-contact 3D scanning techniques, to discover their possible fields of application, their characteristics, and the methodologies used. In particular, metrology issues will be addressed in order to evaluate the quality and reliability of the scans.

Quarter number

Intensive week at the end of the SG8

Prerequisites (in terms of CS courses)

None

Syllabus

Introduction to 3D scanning techniques and metrology
Handling of non-contact 3D digitizing means, realization of first scans
Introduction to point cloud processing software
Identification of the parameters influencing the quality of measurements
Design and implementation of devices to evaluate performance
Realization of one or more case studies
Analysis of the work carried out and formulation of methodological recommendations for the implementation of 3D scanning means

Class components (lecture, labs, etc.)

Practical and experimental work

Grading

Oral defense and writing of an activity report.

Resources

3D scanners

Reverse engineering and 3D reconstruction software

Learning outcomes covered on the course

Identify the different non-contact 3D scanning techniques and their principles
Practice one or more non-contact 3D scanning methods
Determine and classify the different parameters influencing the quality of the measurement
Propose a measurement methodology adapted to the means used

Description of the skills acquired at the end of the course

C1 : C1 Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 : Develop in-depth skills in an engineering field and a family of professions
C6 : Be operational, responsible, and innovative in the digital world

2IN5020 – Semiconductor innovation

Instructors : **Tanguy Phulpin**
Department : **DÉPARTEMENT SYSTÈMES D'ÉNERGIE ÉLECTRIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

Welcome in the semiconductors area. This domain has a really strong impact on our lives and future innovation requires new topologies, new improvements, new researchers. To understand what are the challenges, it is fundamental to possess the basics and to handle them.

After several industrial conferences one Thursday afternoon of November, and after 6 hours of lesson the Monday, let's start in C2n and GeePs laboratory for realization, characterization and simulation.
The Friday is booked for data analyses and report redaction

Quarter number

Intensive week SG6 and SG8

Prerequisites (in terms of CS courses)

none

Syllabus

Energy band model will be described in this lesson. You will study the different semiconductors interfaces with a focus on a PN junction and the FET effect. You will be able to understand how a bipolar transistor or a MOSFET or a solar cell is working. You will estimate the main characteristics of semi-conductors to be able to understand what are the requirement of this domain.
Then the group will be divided in 3, and you will work one day on MOSFET fabrication, one day on electrical characterization and one day on simulation

Class components (lecture, labs, etc.)

A conference the Thursday afternoon one week before. Then the lesson takes place the Monday before going into laboratories to work on the project. The Friday is free for report redaction

Grading

report

Resources

- Teaching staff (instructor(s) names): P. Molinié, T. Phulpin
- Maximum enrollment: 9 binomes, 18 students

Learning outcomes covered on the course

Basics in semi-conductor physic: Energy Band, Electric field, Current density, Field-Effect transistors, PN junction,

photovoltaic cell

Description of the skills acquired at the end of the course

After the short lesson, students will understand the basic knowledge of semiconductors technology.
They will meet professionals, and work in laboratories. They will work on new topics with high technology measurement tools.

2IN5030 – Experimental physics work

Instructors : **Brahim Dkhil**
Department : **DÉPARTEMENT PHYSIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Fundamental Sciences**
Advanced level : **No**

Description

It is an experimental learning in physics that aims to (i) illustrate and experimentally apply the content of CentraleSupélec's physics teaching, (ii) demonstrate creativity and initiative, (iii) work in groups and in a concerted manner, (iv) transmit knowledge. In order to achieve these objectives, the pupils will have at their disposal a set of equipment and apparatus from which, with the help of their teachers/teachers, they will have to imagine and implement their own experiments in order to illustrate the following 5 physical themes: structure of matter, radiation-matter interaction, phase transition, transport phenomena, energy conversion.

Quarter number

Intensive week of the SG6 and SG8

Prerequisites (in terms of CS courses)

Basics in Physics

Syllabus

Each group will be made up of 10 students divided into 5 pairs (one pair = one physical theme) and must have a common thread (guideline). The capacity of reception and supervision (4 teachers) allows a total of 30 students. At the beginning of the sequence, during two half-day sessions, which will be called "preparatory" sessions, and with all the supervisors, the students will have to divide themselves up and will have the free will to define their common thread and the experiences they will have to implement and present in April over 4 days.
During the preparatory sessions, the students will have access to a list of equipment and materials (visit to the InnoPhysLab room + SPMS laboratory equipment) which will be made fully available to them to carry out their experiments. Within a certain limit and according to the needs expressed, small additional equipment may be purchased to complete the equipment already made available.
Each group will have 4 days to set up their experiments in accordance with the physical themes, to take measurements, to criticize the results, and to make a "youtube" type video which will be submitted to an external committee of physics teachers from CentraleSupélec.

Class components (lecture, labs, etc.)

2 sessions of 3 hours to prepare the experimental work
4 days of 7.5 hours of experimental work implementation and presentation

Grading

The evaluation is based on the behaviour and work done during the experimental sessions as well as on the video realized by the students which aims at describing their work

Resources

4 teachers for 30 students distributed into 3 groups of 10 students
Acces to InnoPhys room and SPMS lab equipments

Learning outcomes covered on the course

consolidate their knowledge in Physics
knowhow for mounting an experiment
work in a groupe, exchange and orgnaize the work
develop creativity and initiative
learn how to transmit their knowledge

2IN5050 – Discovery of software defined radio

Instructors : **Jacques ANTOINE**
Department : **DÉPARTEMENT SIGNAL, INFORMATION, COMMUNICATION**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

The radio spectrum is a rare resource shared worldwide by many players for various applications (broadcasting of multimedia content, Internet of Things, 5G, satellite radio navigation systems, transport, etc.). This experimental module aims to allow students to immerse themselves in the world of radio and discover the underlying technologies through practice by participating in a challenge that consists of decoding broadcast signals.

Quarter number

Intensive week SG6 and SG8

Prerequisites (in terms of CS courses)

Signal processing, Modeling, Python. This elective may be an opportunity to put into practice concepts covered in other elective courses (which it is not necessary to have followed): Principles of wireless telecommunications, From information theory to IoT networks, Electronic Systems , Theory of communications, Mobile communications networks.

Syllabus

A first part of the experimental module is devoted to the discovery of the radio spectrum and radiocommunication systems. It introduces the key concepts of software defined radio (SDR, Software Defined Radio).
The students have at their disposal two SDR type cards to design and build a transmitter and a receiver, validate it and test its performance. The objective is to learn all the steps necessary to transform data into a modulated signal, emit it and then detect the signals to decode the useful information, both from a theoretical point of view and functional and hardware architecture.

Secondly, a challenge will be issued to the students: choose a broadcasting system and decode the corresponding signals; for example name of an FM(*) station (RDS(*) system) or position of a civil aircraft (ADS-B(*) system).

(*)ADS-B: Automatic dependent surveillance-broadcast; FM: Frequency Modulation; RDS: Radio Data System.

Schedule for the week:
• Introduction to SDR technology
• Contribution on terrestrial broadcasting systems and on the use of the radio spectrum
• Contribution on digital modulations and realization of a transmission between two SDR cards
• Challenges: choosing a broadcasting and decoding system

Class components (lecture, labs, etc.)

Practical work fed by some theoretical contributions.

Grading

A report will be submitted on the experimental work carried out. A presentation will be made at the end of the challenge to explain the choices made to decode the chosen broadcast system.

Course support, bibliography

Presentation of the standards studied. Course complements.

Resources

Teaching staff: Jacques Antoine, Raul De Lacerda
Software (GNU radio) and hardware (SDR card) tools.

Learning outcomes covered on the course

At the end of this course, students will be able to design and implement wireless digital communication systems from software radio cards. They will be familiar with the main parameters and the operation of a digital transmission chain.

Description of the skills acquired at the end of the course

C1.2 Modeling: using and developing the appropriate models, choosing the correct modeling scale and the relevant simplifying assumptions
C1.3 Solve: solve a problem with a practice of approximation, simulation, and experimentation
C2.1 Deepen a field of engineering sciences or a scientific discipline
C2.2 Import knowledge from other fields or disciplines
C6.3 Process data
C8.1 Build the collective to work as a team

2IN5060 – Audio Signal Processing

Instructors : **Jose Picheral**
Department : **DÉPARTEMENT SIGNAL, INFORMATION, COMMUNICATION**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Engineering Sciences**
Advanced level : **Yes**

Description

Audio signal processing has numerous applications : source separation, source localization, acoustic imaging, study of reverberation room, compression...
Besides, experiments with audio signal have the advantages of being quite simple : the audio sources can easily be controlled (for instance using PC and loudspeakers) and the data are usually acquired using microphones.

Quarter number

Intensive week SG6 and SG8

Prerequisites (in terms of CS courses)

Signal Processing, Statistics and Learning

Syllabus

Three workshops will be addressed during this course.

Room acoustics, reverberation
The sound perceived in a room is significantly different from the sound emitted because of reverberations on the objects and walls of the room. The reverberation effect can be modeled as the convolution of the emitted signal with the impulse response of the room.
The objective of this workshop is to perform experimental measurements and implement the processing to identify the impulse response of different rooms in order to characterize the acoustic environment (e.g. estimation of the reverberation time) and to synthesize realistic signals as they would be heard in the room.

Source separation
Mixing an audio recording consists of mixing different audio tracks to produce one mono track, two stereo tracks, or more (5.1, etc.). Conversely, source separation aims to find these sources, without knowing the gains used to generate the audio tracks, and with more sources than tracks. This type of technique can be used to unmix a music recording or separate speakers in a room.

Detection of noisy points (acoustic imaging)
Acoustic imaging consists of mapping the sound scene in order to obtain an image where each pixel corresponds to the sound intensity emitted by the acoustic sources. With acoustic imaging, we can accurately detect the position of noisy points on an object or in any acoustic scene.
This type of method requires a microphone array of significant size in order to have a sufficient resolution. A network of 32 microphones will be available for measurements.

Class components (lecture, labs, etc.)

Most of the time will be dedicated to practical work.
The theoretical contributions necessary to the understanding of the physical phenomena and treatments will be carried out in the form of short oral interventions of the teachers.

Grading

The work done will be evaluated during a defense in a group of three students.

Resources

The acquisition systems will be made available to the students, and software lib in python will also be provided for the most standard processing.

Learning outcomes covered on the course

For each of the workshops, students will design a measurement protocol, to carry it out and to process the signals. The goal is to develop a methodology to validate the experimental results and evaluate the performance of the proposed processing.

Description of the skills acquired at the end of the course

C1. Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2. Acquire and develop broad skills in a scientific or academic field and applied professional areas
C6. Advance and innovate in the digital world

2IN5070 – Immersion week in Biomaterials

Instructors : **Pedro Esteves Duarte Augusto**
Department : **DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS**
Language of instruction : **ENGLISH**
Type of course : **Elective 2A**
Campus : **HORS CAMPUS**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category :
Advanced level : **No**

Description

There are different rising challenges for the ecological transition, such as developing alternatives with lower environmental impact for traditional materials. This is the case of different petroleum-based materials, plastics, concretes and foams, which can be used as films, sheets, or blocks for packaging, thermal isolation, mechanical protection, building blocks, and biomedical applications, among many other uses. In fact, there is an urgent need to reduce the impact of specific materials, such as the single-use plastics, as well as move the industry towards the concept of integral use of natural resources.

An interesting alternative to face this challenge is producing bio-based materials from biomass, using renewable carbon for structuring new materials. Interesting properties can be obtained by combining biomass of different sources, which can be transformed before or after different strategies of assembling process. However, some drawbacks are frequently seen, in comparison with traditional materials, in relation to physical properties and durability. Therefore, a right balance among technical, ethical, environmental and economic issues must be achieve for each application, being important for CentraleSupélec Engineers to understand this context and to develop alternatives for a changing World.

Syllabus

The Immersion Week will start with a discussion in relation to the problematic and main aspects of biomaterial science, for contextualization and preparing the students for the practical activities (TPs). Different lecturers will be organized and offered by the Chair of Biotechnology of CentraleSupélec and its partners (academic and industrials).

In the following days, the students will develop the TPs, up to a final report and presentation.

The students will be dived in groups. Each group will choose three TPs to follow and one topic to study in depth, making a presentation. Examples of subjects to be developed (updated yearly):

- Production of bio-based plastics and biocomposite through extrusion
- Production of bio-based materials through compression moulding
- Bioprocessing of biomass towards biomaterials: mycelium-based composite
- Mechanical, thermal and hydric properties of biomaterials
- Structure of bioproducts and biomaterials: techniques of evaluation and correlation with properties
- Biomass processing and transformation: valorisation through energy, molecules recovery and biomaterials production
- Structure-process-properties relationships in bioproducts

Class components (lecture, labs, etc.)

The Immersion Week will start with a discussion in relation to the problematic and main aspects of biomaterial science, for contextualization and preparing the students for the practical activities (TPs). Different lecturers will be organized and offered by the Chair of Biotechnology of CentraleSupélec and its partners (academic and industrials).

In the following days, the students will develop the TPs, up to a final report and presentation.

The students will be dived in groups. Each group will choose three TPs to follow and one topic to study in depth, making a presentation.

Grading

The experimental work (care given, autonomy, dynamism) will be evaluated by the supervisors, with individual marks, which represents 25% of the final grade. An oral presentation of 10 to 15 min, followed by questions, will be prepared by each group, considering a topic within the studied ones – the presentation will count for 25% of the final grade. Finally, a report of 10 pages, considering all the obtained data, will represent 50% of the final mark.

Learning outcomes covered on the course

In this immersion week, the students will have the opportunity of processing, producing and evaluating different biomaterials (such as bio-plastics, vegetable concretes, wood, foods, agro-industrial by-products, etc), for different applications (such as packages, construction, automotive, biomedicine, etc). By combining lecturers, practical activities and discussions, the students will develop a judgment about this topic, which will help them to develop innovative approaches to aid the ecological transition.

Description of the skills acquired at the end of the course

C1
C2
C7
C8

2IN5080 – Physics of electrical discharges (cold plasma)

Instructors : **Michael Kirkpatrick, Giacomo GALLI, Emmanuel Odic**
Department : **DÉPARTEMENT SYSTÈMES D'ÉNERGIE ÉLECTRIQUE**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Engineering Sciences**
Advanced level : **No**

Description

Plasma, sometimes referred to as the fourth state of matter, is a globally electrically neutral ionized gas. This neutrality implies that the number of charge carriers of both signs is approximately equal on a spatial scale dependent on both the pressure and degree of ionization of the gas. The latter parameter also determines the temperature of the plasma. In highly ionized plasmas, such as those found in stars or nuclear fusion reactors, temperatures can reach several million Kelvin. In the case of an electric arc, the temperature can reach 5000 K, and in lightning phenomena, it can reach 30,000 K (resulting in thunder).

However, there are also plasmas with low degrees of ionization (on the order of 10^-4), where the electron temperature is on the order of tens of thousands of Kelvin while the gas temperature remains close to ambient, indicating a strong out-of-thermal-equilibrium character. These plasmas are referred to as non-equilibrium or non-thermal plasmas, or cold plasmas.

These plasmas, with St. Elmo's fire being an example illustrating atmospheric electrostatic activity, have found numerous industrial applications. For instance, in the field of surface treatment, low-pressure plasma is used for etching silicon substrates (wafers) through ion bombardment. Atmospheric pressure plasmas are also utilized for surface treatment of polymers to increase their surface energy and confer hydrophilic properties. In the field of flue gas treatment, electrostatic precipitators or electrofilters (Cottrell process - 1907) employ cold plasmas to collect particles. Lastly, the Siemens process has been used since the early 20th century for industrial ozone production, particularly for water treatment. Additionally, the emissive properties of plasmas are also exploited, for example, in lighting using fluorescent tubes or more recently with large-scale displays.

In most cases, plasma is generated by electric discharges, imposing a strong electric field across a gaseous gap using at least a pair of electrodes. This situation can occur whenever high voltage levels are applied to a system. Therefore, plasmas can unintentionally be generated in the production, transportation, and distribution of electrical energy. Discharges can then pose a nuisance and lead to component failures. In the context of electrification in transportation (ground and aerospace), the risk is amplified by the increased voltage in the onboard network.

Whether it is a phenomenon implemented within a reactor or unintentionally produced in an electrical energy transport/conversion system, the plasma itself and its behavior can be described and characterized using the physics of gases and fluid mechanics, and by utilizing typical macroscopic quantities such as density, temperature, pressure, and flow velocity.

Cold plasma is both a highly interesting and complex medium, and the aim of this elective course is to provide students with a first glimpse into the physics of this physical phenomenon by using electric discharges as the object of study to conduct experiments.

Quarter number

Intensive week : SG6 and SG8

Prerequisites (in terms of CS courses)

none

Syllabus

On the first day, students will attend a general lecture on plasmas as a whole class. The class will then be divided into two groups, with pairs formed within each group. One group will explore numerical simulations while the other group conducts experiments. The groups will be switched afterward, allowing all students to experience both the experimental and simulation activities.

At the end of each day, the final hour will be dedicated to a constructive exchange (Q&A) among students, with the support of the professors.

Class components (lecture, labs, etc.)

This course is designed to provide students with a hands-on experience that aims to acquaint them with the physics of discharges, measurement considerations, and the impact of voltage supply profiles on discharge behavior. The practical experiments will be accompanied by theoretical reviews and supplementary materials, as well as multiphysics simulations.

Grading

Project presentation

Course support, bibliography

The students will have access to the following resources:

- All the materials used during the classes,
- A guide document containing the necessary information on experiments, simulations, and theory,
- Scientific articles illustrating various aspects of the activity and the state of the art in different domains,
- Documentation related to the instruments used during the experiments, such as power supplies, vacuum systems, electrical and pressure measurement devices.

Resources

Reconfigurable classroom (18 people) equipped with projector and WiFi, COMSOL Multiphysics, high-voltage power supplies, vacuum chambers, and pumping systems, and electrical discharge measurement systems.

Learning outcomes covered on the course

The objective is to familiarize students with the study of electrical discharges (cold plasmas) and develop their critical thinking skills during hands-on experiments and simulations. The aim is to teach them to work together in groups, connecting theoretical concepts with experimental and simulation results. At the end of each day, students should learn to ask questions and/or effectively communicate and explain what they have learned in a clear and concise manner to those who inquire.
Students will be required to deliver a 15-minute group presentation, adhering to the allotted time, which should be clear, concise, and coherent. In this presentation, they will describe and interpret the obtained results, provide constructive critiques of the analyses conducted and the methods employed.

Description of the skills acquired at the end of the course

C1: Analyzing, designing, and implementing complex systems with scientific, technological, human, and economic components.
C8: Leading a project or a team.
C2: Developing an in-depth competence in a scientific or sector-specific field and a related set of professions.
C7: Knowing how to persuade or convince.

2IN5106 – Marketing and its tools: towards responsible marketing ?

Instructors : **Emmanuel Helbert**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Business Sciences**
Advanced level : **No**

Description

What is the use of marketing for an engineer? The objective of this course is to show that marketing is not intended to sell useless products, but can be a lever for detecting, initiating and accompanying major societal changes and a driver of technological innovation by positioning it as a means and not an end in itself. The different concepts and tools will be approached from the engineer's point of view by illustrating how they support his job.

Quarter number

Intensive week SG6

Prerequisites (in terms of CS courses)

None

Syllabus

- 1. Introduction:
- Definitions
- corporate/marketing strategies
- strategic/operational marketing
- Impact of sustainable development on Marketing - Opportunity or constraints

2. The market :

- a. Markets
- b. The consumer
- c. Studies
- d. Tools: SWOT, PESTEL

3. Marketing strategy

- a. Segmentation
- b. Targeting
- c. Positioning

4. Operational marketing

- a. Marketing mix and sustainable development
- b. Brand management

- c. Product Management
- d. Distribution
- e. Awards
- f. Communication and corporate social responsability
- g. Focus: Digital marketing, content marketing, B2B marketing

5. Marketing today

- a. Lean Start-Up
- b. Design Thinking

Class components (lecture, labs, etc.)

Alternating between presentation of concepts and group work (3-4 students). Each group will explore a project that will be the common thread of the week allowing the concepts to be put into practice.

Grading

Alternance entre la présentation des concepts et le travail en groupe (3-4 élèves). Chaque groupe explorera un projet qui sera le fil rouge de la semaine permettant de mettre les concepts en pratique.

2IN5110 – Ethics and Responsibility

Instructors : **Jean-Marc Camelin**
Department : **DÉPARTEMENT DÉVELOPPEMENT PROFESSIONNEL ET MÉTIERS DE L'INGÉNIEUR**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Business Sciences**
Advanced level : **Yes**

Description

This elective course addresses the issue of ethics and responsibility for an engineer, using concrete situations described during the 1 week seminar (witnesses, videos, theoretical contributions) as engineers are facing them, and leads to an awareness and a capacity of questioning individually the adequacy between their actions and decisions and their own values.

High-level engineers have a key role in the evolution of our society. This course is designed for students intending to pursue a career either in management, potentially as very high-level decision makers (decision making in conscience), or in research, including fundamental research (representation of future uses of their research). Objectives are to:

- Expose each student to the ethical, social, societal, economical and political consequences of their actions as an engineer, in an increasingly multicultural environment
- Help students develop an awareness of ethical and societal issues in their future professional career
- Educate students on what influences their decision-making, beginning with their choice of curriculum and job

Quarter number

Intensive week at the end of the SG6

Prerequisites (in terms of CS courses)

Advanced level elective requesting to have done the 2nd year API on ethics

Syllabus

1. Introduction to ethics: responsibility, concept, history, reference texts, tangible actions involved, meaning.
2. Illustration of the problem: labor and work (concept, role, suffering at work, empowerment), environment (sustainable development, decisions, impact), world global issues
3. Understanding the System: the current system (capitalism, economic regulation, impact on the actions of decision makers, measures, GDP), alternatives (how to think the world differently, microcredit, virtual economy), science and the engineer of the 21st century (role of the engineer within the system, his/her influence on ethical issues, research and its impact)
4. Ethic as an action: individual issues (I decide and act in conscience), political decision (provide guidance to the whole society), broadening the issue (global-international-national-local levels, time representations in the short-medium-long terms, the CEO decision-making process: strategy, innovation), you as a student (how I understand my environment and how I project myself into the future as an engineer, my gap year, my professional dreams)

Class components (lecture, labs, etc.)

Alternate plenary sessions and half-promo workshops, conferences, Alumnis witnesses

Grading

Oral presentation of group project conducted throughout the seminar

Active participation during conferences
Competencies auto-evaluation and peer-evaluation

Course support, bibliography

Course material, bibliography: provided to students in the introduction of the course

Resources

Course material, bibliography: provided to students in the introduction of the course
Teaching team:

- Fabienne Bergé - enseignante coordinatrice de pôle projet et de l'électif DYW – psychologue du travail
- Bruno Lefèbvre - Associé Fondateur Alteralliance - spécialiste psycho-dynamique du travail
- Patricia Midy - enseignante APP/API - coach indépendante
- Gilles Lecerf - Enseignant HEC en Philosophie & technologie
- Conférenciers extérieurs

Learning outcomes covered on the course

- To take the necessary step back from the professional context to consider the ethical aspect of the action
- Understand the constraints of the socio-economic system to be able to question them
- Critical thinking and discernment of the system
- Transforming difficulties and constraints into opportunities to pursue one's career while respecting one's personal ethics

Description of the skills acquired at the end of the course

C5.2 Listening, making oneself understood and working with actors of diversity, cultures, codes, training, disciplines, etc. varied

C7 Know how to convince

C9 (C9.1-2-3-4) Think and act as an ethical, responsible and honest engineer, taking into account the environmental, social and societal dimension

2IN5120 – Public Finances

Instructors : **Pierre Bertinotti**
Department : **CAMPUS DE METZ**
Language of instruction : **FRENCH**
Type of course : **Elective 2A**
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category : **Business Sciences**
Advanced level : **No**

Description

from factual data: concepts, procedures, figures.., allow each student to develop his or her own thinking on the major issues of public finances.

Quarter number

semaine bloquée SG8

Prerequisites (in terms of CS courses)

none

Syllabus

Introduction
Public finances: what are we talking about?
1. The major issues related to public spending and taxation :
Relationships with politics, the economy and society
2. Government finances :
Drawing up the budget:
Content: missions, programs, actions
The procedure: the European semester and the national semester
The State's financial resources: taxation and debt
Budget implementation: the main business rules
Control of expenditure and evaluation of actions
3. Local authority finances :
Who finances what? Powers and expenditure
The financial autonomy of local authorities: local taxation
Preparation, execution and control of local government budgets
4. Social protection accounts :
The scope of social protection: the various social benefits
The financing of social protection: contributions, taxes and public contributions
Social protection: a political issue

Class components (lecture, labs, etc.)

the active participation of students will be favoured: briefs Introductory lectures, case studies, role-playing...
Collective reflection will be encouraged.

Grading

grouped in groups of 3 or 4, the students will write a thesis. of about fifteen pages on a theme related to the course, decided in agreement with the teacher.
The presentation can be made orally using the usual computer and digital tools.

Course support, bibliography

Bibliography

1. Waserman F., Les finances publiques, La Documentation Française, 10th edition, 2023.
2. Bouvier M., Les finances locales, L.G.D.J, 18th edition, 2020
3. Bouvier M., Esclassan M.-C., Lasalle J.-P., Finances publiques, L.G.D.J, 19th edition, 2020

Useful links

1. INSEE https://www.insee.fr/fr/accueil
2. The platform for public finance, the State budget and public performance https://www.budget.gouv.fr
3. Public life https://www.vie-publique.fr
4. Local authorities https://www.collectivites-locales.gouv.fr
5. Légifrance The public service for the dissemination of law https://www.legifrance.gouv.fr
6. Court of Auditors https://www.ccomptes.fr/fr
7. National Assembly https://www.assemblee-nationale.fr
8. Senate http://www.senat.fr
9. Social Security https://www.securite-sociale.fr/accueil#
10. Direction de la recherche, des études, de l'évaluation et des statistiques: L'expertise statistique publique en santé et social https://drees.solidarites-sante.gouv.fr/systeme-de-protection-sociale
11. Agence France Trésor https://www.aft.gouv.fr
12. European Commission https://ec.europa.eu/info/index_fr

Resources

A PowerPoint presentation will be used to support the course. It will be accompanied by podcasts, video sequences and consultations of online sites.

Learning outcomes covered on the course

At the end of the course, the student will be able to understand the daily information on public finances, whether it is about the State, local authorities, social protection or Europe. He or she will be able to place this information in its political and economic context. This data relating to public finance is an essential element of the company's environment. They influence companies' investment and research decisions. They structure the economic and social behavior of all economic agents

Description of the skills acquired at the end of the course

Legal skills: notions of public law, parliamentary law, constitutional law, budget law
Political science skills: functioning of the State, local authorities and European institutions
Economic skills: the interactions between public finance and the economy at the local, national and European levels
General skills to allow each student to deepen his or her political reflections

LANGUAGE AND CULTURE COURSES

LC0100 – English

Instructors : **Mark Pitt**
Department : **DÉPARTEMENT LANGUES ET CULTURES**
Language of instruction : **ENGLISH**
Type of course : **Language**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES, CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **21,00**

Description

In 1st and 2nd years two courses per year are offered, each extending over two consecutive sequences.
3rd year classes are of varying duration, depending on student profile.

Quarter number
Two courses per year, each lasting two sequence, 1 and 2 and / or 3 and 4

Prerequisites (in terms of CS courses)
none

Syllabus

General and thematic courses are on offer, depending on the level and the availability of the student

Class components (lecture, labs, etc.)

Student-centred active learning, flipped classroom, whole class or group activities. One hour minimum per week of homework to prepare or prolong in-class activities.

Grading

Continuous assessment (various spoken and written exercises) counting for at least 80% of the final grade.

Course support, bibliography

Varied: audio and video, written documents, news articles, documentaries, works of Literature, English language textbooks, depending on the course taken.

Learning outcomes covered on the course

Consolidate and develop the four basic language skills (reading, writing, listening and speaking).

- C5: Consolidate and develop intercultural skills and comprehension essential to an international career.
- C7: Improve one's persuasive skills
- Give students an awareness of language that will allow them to develop their self learning skills propose a varied and innovative approach to language learning.

Description of the skills acquired at the end of the course

1. The student will have progressed towards (or even beyond) the C1 level required for the CentraleSupélec diploma.
2. Other skills (C5, C7) will have been reinforced.

LC0200 – French as a Foreign Language

Instructors : **Geraldine Ofterdinger**
Department : **DÉPARTEMENT LANGUES ET CULTURES**
Language of instruction : **FRENCH**
Type of course : **Language**
Campus : **CAMPUS DE METZ, CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **21,00**

Description

This document is for 1st, 2nd and 3rd year students.

Quarter number

S5 from September to January S6 from February to June

Prerequisites (in terms of CS courses)

None.

Syllabus

Those weekly courses are offered at several levels, depending on the results of the placement test. Classes are organized as practical workshops focusing on oral understanding and communication, written understanding and communication, structural proficiency (grammar, vocabulary). Students will work individually or in groups on themes related to contemporary French culture in relation to its historical past.

Class components (lecture, labs, etc.)

A placement test will determine the level of the course: A1, A1, B1, B2, or C1 (European reference framework)

Grading

The evaluation is organized in two ways: continuous assessment and control of the end of half-year.

Course support, bibliography

Specific to each course and group level: printed documents (press, literature), audio/video (films, recordings), textbooks

Learning outcomes covered on the course

Develop and solidify the four language competences (written and oral comprehension, written and oral expression) to communicate in the academic, professional and/or personal environments. Develop and solidify the tools of intercultural understanding to allow students to engage in the discovery of the culture. Allow students to develop their learning process in an autonomous and responsible wayOffer various innovative approaches suited to individual needs

Description of the skills acquired at the end of the course

Master French for academic courses, as the common language of international communication on campus, and as a professional communication language. Master French as an effective communication tool to understand contemporary French culture.

LC0300 – German

Instructors : **Daniela Moncys Moncevicius**
Department : **LANGUES ET CULTURES, DÉPARTEMENT LANGUES ET CULTURES**
Language of instruction : **GERMAN**
Type of course : **Language**
Campus : **CAMPUS DE RENNES, CAMPUS DE METZ, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **28**
On-site hours (HPE) : **21,00**

Description

General German courses from level A0 to C1, with specialization (thematic courses) possible from level B1+.
Possibility of E-Tandem with the RWTH Aachen for advanced students

Quarter number

S5 from September to January S6 from February to June

Prerequisites (in terms of CS courses)

Beginner courses (A0) are only possible in the first semester of the first year.
If you have previously studied German, the minimum level required at the end of the first year is A2+ and at the end of the second year B1-.

Syllabus

GENERAL GERMAN
Beginner level: Practice of oral and written skills. Introduction to the culture and current affairs of German-speaking countries.
Level A1-B1: Acquisition of basic skills, with particular emphasis on oral and written language. Intercultural approach to German-speaking countries and cultures.
THEMATIC COURSES: From level B1+ Practice of the German language at an intermediate and advanced level by means of thematic sequences: economy, science, history, current events, culture, arts and others - also depending on the motivation of the learners - and by means of weekly debates. All courses include written and oral grammar and structure exercises. Preparation for the Goethe Institute certificates (B1 to C2) possible.

Class components (lecture, labs, etc.)

After a test, each student is placed in a course corresponding to his/her level:A0, A1-A2, B1-B2, C1 (according to the Common European Framework of Reference).
Throughout his or her schooling, the student will follow weekly classes of 1.5 hours each, between which he or she will do individual or group work of about 1 hour.
The principles of the flipped classroom can be applied, leaving full space during the class session for interaction, exchange and role-playing.

Grading

Continuous assessment and involvement in classes at least 80%, up to 100%; possibility of an end-of-semester exam (written exam/audit/oral test) which counts for a maximum of 20% of the grade
Written and oral assessment of the required exit level at the end of the language course in 3A: A2- for those who have started German at CS, B1 or higher for those who have studied German before

Course support, bibliography

A variety of materials: textbooks, audio, video, written documents, interactive exercises that emphasize language practice and teamwork.

Resources

Diverse, varied, communicative and interactive courses adapted to the interests and needs of the learners and focused on the major themes and trends of our societies, the culture and economic, political and social current events in German-speaking countries as well as interculturality

Learning outcomes covered on the course

To consolidate and develop the four language skills (written and oral comprehension, written and oral expression) which will provide the tools to communicate in an internationalized and varied school, professional and/or personal environment. To consolidate and develop the tools of intercultural understanding that will allow students to initiate cultural openness and to approach the International. To allow each student to develop the means to continue learning by encouraging autonomy, responsibility, teamwork and project work as well as critical thinking in the learning process. To propose, throughout the three years of study, varied and innovative approaches allowing each student to find himself in a suitable teaching program.

Description of the skills acquired at the end of the course

Understand and express oneself in written and spoken German, in everyday life as well as in a professional and academic context (internships, academic exchanges, e-tandem ...). Acquire intercultural skills allowing better communication with interlocutors in German-speaking countries.
Consolidate the engineer's skills C5 and C7 (intercultural skills, arguing and convincing)

LC0400 – Spanish

Instructors : **Antonio Barrejon Lopez**
Department : **LANGUES ET CULTURES, DÉPARTEMENT LANGUES ET CULTURES**
Language of instruction : **SPANISH**
Type of course : **Language**
Campus : **CAMPUS DE RENNES, CAMPUS DE METZ, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **28**
On-site hours (HPE) : **21,00**

Quarter number

S5 from September to January S6 from February to June

Syllabus

SPANISH GENERAL Beginner level : Practice of oral and written skills. Awareness of the culture and current affairs of Spain and Latin America. Level A1-B1: Reinforcement of basic notions, with special emphasis on oral and written language. Openness to the civilization of Spain and Latin America. THEMATIC COURSES - From level B2 onwards Although the linguistic aspect remains an essential component of this course, the materials used allow an approximation to the historical and cultural realities of Spanish-speaking countries. -Spanish civilization and culture. -Latin American civilization and culture. -Economic Spanish. -Cinema. -Preparation for the official level exam, DELE ("Diploma de Español Lengua Extranjera") of the Cervantes Institute.

Class components (lecture, labs, etc.)

Following a test, students are placed in level groups. Lessons are 1.5 hours long.

Grading

CS: Continuous assessment (various spoken and written exercises) counting for at least 80% of the final grade.

Learning outcomes covered on the course

Consolidate and develop the four main language skills (reading, writing, listening and speaking) Consolidate and develop intercultural skills and comprehension essential to an international careerGive students an awareness of language that will allow them to develop their self learning skills propose a varied and innovative approach to language learning

Description of the skills acquired at the end of the course

Understand and express yourself in Spanish, both in everyday life and in a professional and academic context (internships, academic exchanges ...). Acquire intercultural skills that will enable you to communicate better with people in Spanish-speaking countries.

LC0500 – Italian

Instructors : **Claude Mezin-Wilkinson**
Department : **DÉPARTEMENT LANGUES ET CULTURES, LANGUES ET CULTURES**
Language of instruction : **ITALIAN**
Type of course : **Language**
Campus : **CAMPUS DE METZ, CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **28**
On-site hours (HPE) : **21,00**

Syllabus

General language course at all levels (beginner to advanced) focussing on: oral understanding and expression (pronunciation, intonation, rhythm, lexicon, structures), interaction; Written understanding and expression (lexicon, structures); Acquisition of the tools enabling successful communication; Increased cultural and cross cultural awareness.

Class components (lecture, labs, etc.)

Following a test, students are placed in level groups.
Student's levels are evaluated each semester, and the groups made accordingly.
Lessons are 1.5 hours long.

Grading

Continuous assessment (80-100%) Written exam / listening-speaking test at the end of each semester (0-20%)

Learning outcomes covered on the course

Consolidate and develop the main language skills (reading, writing, listening and speaking)
Consolidate and develop intercultural skills and comprehension essential to an international career
Give students an awareness of language that will allow them to develop their self learning skills
Propose a varied and innovative approach to language learning.

Description of the skills acquired at the end of the course

C5: Be comfortable in a multicultural and international environment, C5.1 more specifically.
At the end of this course, the student will be able to communicate according to the skills of the CEFR, with increased fluency and accuracy.

LC0600 – Portuguese

Instructors : **Claude Mezin-Wilkinson**
Department : **DÉPARTEMENT LANGUES ET CULTURES, LANGUES ET CULTURES**
Language of instruction : **PORTUGUESE**
Type of course : **Language**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES, CAMPUS DE METZ**
Workload (HEE) : **28**
On-site hours (HPE) : **21,00**

Quarter number

S7 and S8

Syllabus

General language course at all levels (beginner to advanced) focussing on: Oral understanding and expression (pronunciation, intonation, rhythm, lexicon, structures), interaction; Written understanding and expression (lexicon, structures); Acquisition of the tools enabling successful communication; Increased cultural and cross cultural awareness.

Class components (lecture, labs, etc.)

Following a test, students are placed in level groups.
Student's levels are evaluated each semester, and the groups made accordingly.
Lessons are 1.5 hours long.

Grading

Continuous assessment (80%) Written exam / listening-speaking test at the end of each semester (20%)

Learning outcomes covered on the course

Consolidate and develop the main language skills (reading, writing, listening and speaking)
Cconsolidate and develop intercultural skills and comprehension essential to an international career
Give students an awareness of language that will allow them to develop their self learning skills
Propose a varied and innovative approach to language learning.

Description of the skills acquired at the end of the course

C5: Be comfortable in a multicultural and international environment, C5.1 more specifically.
At the end of this course, the student will be able to communicate according to the skills of the CEFR, with increased fluency and accuracy.

LC0700 – Chinese 2A

Instructors : **Claude Mezin-Wilkinson**
Department : **LANGUES ET CULTURES, DÉPARTEMENT LANGUES ET CULTURES**
Language of instruction : **CHINESE**
Type of course : **Language**
Campus : **CAMPUS DE RENNES, CAMPUS DE METZ, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **28**
On-site hours (HPE) : **21,00**

Syllabus

General language course at all levels (beginner to advanced) focussing on: Oral understanding and expression (pronunciation, intonation, rhythm, lexicon, structures), interaction; Written understanding and expression (lexicon, structures); Acquisition of the tools enabling successful communication; Increased cultural and cross cultural awareness.

Class components (lecture, labs, etc.)

Following a test, students are placed in level groups.
Student's levels are evaluated each semester, and the groups made accordingly.
Lessons are 1.5 hours long.

Grading

Continuous assessment (80%) Written exam / listening-speaking test at the end of each semester (20%)

Learning outcomes covered on the course

Consolidate and develop the main language skills (reading, writing, listening and speaking)
Consolidate and develop intercultural skills and comprehension essential to an international career
Give students an awareness of language that will allow them to develop their self learning skills
Propose a varied and innovative approach to language learning.

Description of the skills acquired at the end of the course

C5: Be comfortable in a multicultural and international environment, C5.1 more specifically.
At the end of this course, the student will be able to communicate according to the skills of the CEFR, with increased fluency and accuracy.

LC0800 – Japanese

Instructors : **Claude Mezin-Wilkinson**
Department : **DÉPARTEMENT LANGUES ET CULTURES, LANGUES ET CULTURES**
Language of instruction : **JAPONESE**
Type of course : **Language**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE METZ, CAMPUS DE RENNES**
Workload (HEE) : **28**
On-site hours (HPE) : **21,00**

Description

Syllabus

General language course at all levels (beginner to advanced) focussing on: Oral understanding and expression (pronunciation, intonation, rhythm, lexicon, structures), interaction; Written understanding and expression (lexicon, structures); Acquisition of the tools enabling successful communication; Increased cultural and cross cultural awareness.

Class components (lecture, labs, etc.)

Following a test, students are placed in level groups.
Student's levels are evaluated each semester, and the groups made accordingly.
Lessons are 1.5 hours long.

Grading

Continuous assessment (80%) Written exam / listening-speaking test at the end of each semester (20%) In case of a justified absence to one of the intermediary examinations, the grade of this latter is replaced by the grade of the final examination

Learning outcomes covered on the course

Consolidate and develop the main language skills (reading, writing, listening and speaking)
Consolidate and develop intercultural skills and comprehension essential to an international career
Give students an awareness of language that will allow them to develop their self learning skills
Propose a varied and innovative approach to language learning.

Description of the skills acquired at the end of the course

C5: Be comfortable in a multicultural and international environment, C5.1 more specifically.
At the end of this course, the student will be able to communicate according to the skills of the CEFR, with increased fluency and accuracy.

LC0900 – Russian

Instructors : **Claude Mezin-Wilkinson**
Department : **LANGUES ET CULTURES, DÉPARTEMENT LANGUES ET CULTURES**
Language of instruction : **RUSSIAN**
Type of course : **Language**
Campus : **CAMPUS DE RENNES, CAMPUS DE METZ, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **28**
On-site hours (HPE) : **21,00**

Syllabus

General language course at all levels (beginner to advanced) focussing on: Oral understanding and expression (pronunciation, intonation, rhythm, lexicon, structures), interaction; Written understanding and expression (lexicon, structures); Acquisition of the tools enabling successful communication; Increased cultural and cross cultural awareness.

Class components (lecture, labs, etc.)

Following a test, students are placed in level groups.
Student's levels are evaluated each semester, and the groups made accordingly.
Lessons are 1.5 hours long.

Grading

Continuous assessment (80%) Written exam / listening-speaking test at the end of each semester (20%) In case of a justified absence to one of the intermediary examinations, the grade of this latter is replaced by the grade of the final examination.

Learning outcomes covered on the course

Consolidate and develop the main language skills (reading, writing, listening and speaking)
Consolidate and develop intercultural skills and comprehension essential to an international career
Give students an awareness of language that will allow them to develop their self learning skills
Propose a varied and innovative approach to language learning.

Description of the skills acquired at the end of the course

C5: Be comfortable in a multicultural and international environment, C5.1 more specifically.
At the end of this course, the student will be able to communicate according to the skills of the CEFR, with increased fluency and accuracy.

LC1000 – Arabic

Instructors : **Claude Mezin-Wilkinson**
Department : **DÉPARTEMENT LANGUES ET CULTURES, LANGUES ET CULTURES**
Language of instruction : **ARABIC**
Type of course : **Language**
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE METZ, CAMPUS DE RENNES**
Workload (HEE) : **28**
On-site hours (HPE) : **21,00**

Syllabus

General language course at all levels (beginner to advanced) focussing on: Oral understanding and expression (pronunciation, intonation, rhythm, lexicon, structures), interaction; Written understanding and expression (lexicon, structures); Acquisition of the tools enabling successful communication; Increased cultural and cross cultural awareness.

Class components (lecture, labs, etc.)

Following a test, students are placed in level groups.
Student's levels are evaluated each semester, and the groups made accordingly.
Lessons are 1.5 hours long.

Grading

Continuous assessment (80%) Written exam / listening-speaking test at the end of each semester (20%) In case of a justified absence to one of the intermediary examinations, the grade of this latter is replaced by the grade of the final examination.

Learning outcomes covered on the course

Consolidate and develop the main language skills (reading, writing, listening and speaking)
Consolidate and develop intercultural skills and comprehension essential to an international career
Give students an awareness of language that will allow them to develop their self learning skills
Propose a varied and innovative approach to language learning.

Description of the skills acquired at the end of the course

C5: Be comfortable in a multicultural and international environment, C5.1 more specifically.
At the end of this course, the student will be able to communicate according to the skills of the CEFR, with increased fluency and accuracy.

LC1200 – Hebrew

Instructors : **Claude Mezin-Wilkinson**
Department : **DÉPARTEMENT LANGUES ET CULTURES, LANGUES ET CULTURES**
Language of instruction : **HEBREW**
Type of course : **Language**
Campus : **CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY, CAMPUS DE METZ**
Workload (HEE) : **28**
On-site hours (HPE) : **21,00**

Syllabus

General language course at all levels (beginner to advanced) focussing on: Oral understanding and expression (pronunciation, intonation, rhythm, lexicon, structures), interaction; Written understanding and expression (lexicon, structures); Acquisition of the tools enabling successful communication; Increased cultural and cross cultural awareness.

Class components (lecture, labs, etc.)

Following a test, students are placed in level groups.
Student's levels are evaluated each semester, and the groups made accordingly.
Lessons are 1.5 hours long.

Grading

Continuous assessment (80%) Written exam / listening-speaking test at the end of each semester (20%)

Learning outcomes covered on the course

Consolidate and develop the main language skills (reading, writing, listening and speaking)
Consolidate and develop intercultural skills and comprehension essential to an international career
Give students an awareness of language that will allow them to develop their self learning skills
Propose a varied and innovative approach to language learning.

Description of the skills acquired at the end of the course

C5: Be comfortable in a multicultural and international environment, C5.1 more specifically.
At the end of this course, the student will be able to communicate according to the skills of the CEFR, with increased fluency and accuracy.